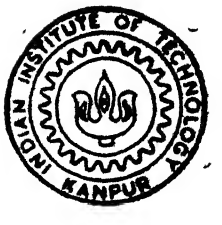
TECHNOLOGICAL SELECTION OF MACHINES IN FLEXIBLE MANUFACTURING ENVIRONMENT

by

YASHVEER SINGH RATHOR



DEPARTMENT OF INDUSTRIAL AND MANAGEMENT ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

JULY, 1994

TECHNOLOGICAL SELECTION OF MACHINES IN FLEXIBLE MANUFACTURING ENVIRONMENT

A Thesis Submitted
in Partial Fulfillment of the Requirements
for the Degree of

Master of Technology

by

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to the

DEPARTMENT OF INDUSTRIAL AND MANAGEMENT ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

JULY, 1994.

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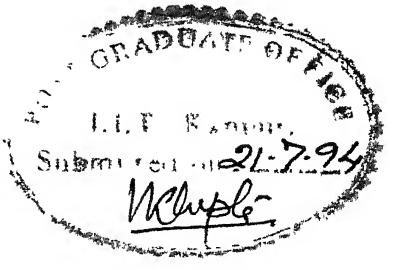

CERTIFICATE

It is certified that work on the thesis entitled " Technological Selection of Machines in Flexible Manufacturing Environment ", by Mr Yashveer Singh Rathor, has been carried out under my supervision and that this work has not been submitted elsewhere for the award of a degree.

(Dr KRIPA SHANKER)

July, 1994

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ABSTRACT

The present work is aimed at providing a solutions to the problem of machine selection in a manufacturing firm of moderate size with a variable demand for finished products. The period wise demand of finished products taken from the MPS is the input to the system. The bill of materials is used to explode the period wise demand of products to that of the components required for their assembly.

The part features of all these components is the other input to the system. The selection of technologically suitable machines for the machining operations required to manufacture the component parts from those that are available is performed using a method devised in the present work This method is evolved by synthesizing the two important schemes of process planning namely the generative system and the variant system.

The system creates and maintains data bases on product structure, part features and machine capability. All the operations required for creating and maintaining these data bases are built into the system. The designed system is implemented using Borland C^{++}. The object oriented features of the language have been used extensively The code is compact and efficient.

The implementation is designed to be an interactive application. All the operations required for creating and maintaining the data bases, registering the product demand, and for performing the other steps incidental to the final selections of machines are performed by a single integrated system Although the implementation has not been designed to handle large data bases the essential system in eminently scale able.

ACKNOWLEDGMENT

I would like to thank to my friends of the 92 batch, the junior batch and the Ph.D. scholars of I.M.E for making my stay here interesting and rewarding. I wish them the best of luck in the pursuit of their chosen aims in life

July, 94. Yashveer Singh Rathor

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CHAPTER I

INTRODUCTION

Production systems in the real world are required to deal with the demand of a large number of different products. In any particular period the Master Production Schedule (MPS) would require the manufacture of a subset of the total set of products that a production facility can manufacture. Also the quantities of each of these different products that are to be manufactured is likely to vary from period to period. The combination of period wise demand is therefore, likely to change from period to period. Products are in most cases constituted of assemblies, which in turn have their own subassemblies and so on, depending on the depth of the product structure. A variation in the demand of finished products would translate into a variation in demand of it's the individual components that are actually manufactured, or procured from external sources. It is the variation of demand of these end components that is of interest from the point of view of management of the manufacturing system, planning, scheduling and control. There are three basic approaches that a firm can adapt to deal with the problem of ensuring the availability of components.

(a) The firm can smooth out erratic demand by holding inventories.

(b) The firm can produce a certain number of components and meet additional demand by subcontracting or by purchasing in the open market.

(c) The firm may choose to adapt a flexible manufacturing approach in designing its production facility.

Holding inventories requires the commitment of storage space, the blocking of working capital and the problem of planning how much of which item to hold. The adoption of this approach, to an extent, frees the production planning

system from being slavishly demand driven and encourages schedules that make optimal use of the firm's production resources The problem of planning the size of inventories however, requires as inputs demand forecasts, cost of lost sales, change over cost and the inventory holding cost. Some of the above quantities are either qualitative or probabilistic and there are obvious difficulties in assigning to them specific values Inventory holding cost, for example, includes the cost incurred in reserving storage space as well as the cost of blocked capital, it may not always be possible to associate precise costs with one or both of these quantities. Further in real life the working capital and space available to hold inventories may be limited.

The addition of flexible manufacturing capability offers a more direct solution to the problem of coping with variation in demand of end items. Flexible manufacturing capability can be achieved either by adding machines with processing flexibility or by use of group technology (GT). .GT involves the classification of the firm's product range into part families, the machines required for their manufacture can then be grouped together, each group specializing in the manufacture of one particular part family (Burbidge [1]). Evidently this approach leads to a considerable simplification in the firms production planning and scheduling operations by reducing the number of variables involved. Flexibility in the output can be achieved by scheduling and routing strategies with or without the use of machines with processing flexibility (i.e. machines that can produce a variety parts).

In case a manufacturing firm plans to cope with variation in demand by the addition of machines with processing flexibility to its existing production facility, it would have to select machines that can successfully manufacture all the different combination of period wise demand. For this the firm will require a decision making system that can select suitable machines from those that are

1.1 FLEXIBLE ASSEMBLY

Automated assembly machines have several workstations and use a synchronous transfer system. These include dial indexing, machines, many in-line assembly systems and certain carousel systems. The measurement of performance are production rates, uptime efficiency, and cost (Groover [2]).

The typical operation occurring at a workstation of a assembly machine is one in which a component is added or joined in some fashion to a existing assembly. The existing assembly consists of a base part plus the components assembled to it in the previous stations. The base part is launched onto the line either at or before the first station. The components that are added must be clean, uniform in size and shape, of high quality and consistent orientation. A defective part entering the system can result in jamming and shutdown of the entire system.

Assembly is traditionally a labor intensive activity in the industry. Assembly operations are also highly repetitive, for this reason it is a logical candidate for robotics applications. However assembly work typically involves diverse and sometimes difficult tasks, often requiring adjustments to be made in the parts that do not quite fit together. A sense of feel is often required to achieve the close fitting of parts. Inspire of the difficulties technological advances in this area has been pursued because of it's economic importance. In high production of relatively simple products, fixed automation described earlier in this section is used. Robot are usually at a disadvantage in a high-production situation because they cannot perform as quickly as fixed automation systems

The most appealing area for robot application is in the production of a mixture of similar products or models in the same workcell or assembly line.

various other small mechanical and electrical components. These types of products are usually made in small batches on a manual assembly line. However the pressure to reduce inventories has made mixed-model lines more attractive. What makes robots useful in these assembly applications is their capability to execute programmed variations in the work cycle to accommodate different configurations.

1.2 PROCESS PLANNING AND MACHINE SELECTION

The different combinations of period wise demand of products can be arrived at by studying the trends in the period wise demand of the earlier periods and by evaluating the factors that are likely to influence demand in the future. The set of machines that is finally selected should be capable of manufacturing all the projected demand combinations with consistent efficiency.

In manufacturing firm of moderate size a large number of products would ordinarily constitute it's product range. As mentioned earlier, these products may, in turn, have further subassemblies. In any given period only a subset of the total product range will be required to be manufactured in the quantities specified in the MPS. The choice of machines would depend on the types of operations that are involved in the production of end components of the products specified in MPS. The number of machines from which the final selection has to be made is also likely to be large. Clearly a workable system for machine selection would have to have a mechanism automatically translating the period wise demand of products into the demand of end components. It must then locate the operations that would be required to produce each end component and on the basis of this data it must select machines from those that are available. The key element in such a system would be the subsystem that finds the sequence of operations required to produce each part and selects suitable machines for each

as input, find the part features of each part and short list those machines that can perform a given operation in an more efficient manner. In other words it should perform many of the important functions of Computer Aided Process Planning (CAPP).(Chang and Wysk [3]).

1.3 REVIEW OF EARLIER WORK

Available literature on automated process planning deals mainly with the recognition of geometric features and with the construction of a process plan given the part features. Each of these steps in the automated construction of a process plan has received considerable attention. Partial solutions to various subsections of the overall problem have been proposed by various researchers (Lin and Bedworth [4], Gavankar [5], Zhao et all [6] etc). A review of the available literature reveals that comprehensive solutions to the problems of feature recognition and subsequent construction of a process plan are usually difficult to find. Two popular schemes for the automated generation of a process plan that were considered in detail and from which the structure of the part coding scheme was evolved are the Variant system and Generative system (Lin and Bedworth [4]).

Variant CAPP system develops process plans based on similar process plans for existing parts that have been classified and coded using GT. Standard plans for identified part are first constructed and stored in a data base with the GT code as retrieving key. A part is classified and coded into one of the part families and the corresponding standard process plan is retrieved from data base. Since there can only be limited number of standard plans, human modifications to standard plans are normally necessary, especially for new parts that differ from those in existing families in certain details. Clearly this scheme of is not general

enough to be useful in all manufacturing environments particularly when certain custom made parts are to be manufactured.

Generative CAPP system is a system that can synthesize process information contained in a GT code in order to create a process plan for a new part automatically. Part design data is an input to the system. A unique process plan is generated based on process planning decision rules and algorithms that have been incorporated into the system. The advantages of this scheme can be briefly summed up as.

(a) consistent process plans can be generated efficiently;

(b) new parts can be planned as easily as existing parts;

(c) linking the system with an automated manufacturing system can provide detailed real time control information.

For the implementation of such a scheme a comprehensive list of part features and a scheme for coding these features has to be constructed Obvious difficulties exist in the construction a exhaustive list of part features and subsequent coding of these features in an unambiguous manner, without the code becoming disproportionately long, defeating the very purpose of coding. Additionally, formulation and incorporation of decision rules into a computer model requires a major effort .

Lin and Bedworth [4] discuss a Semi-generative approach to process planning for parts using a GT coding scheme. They have demonstrated the usefulness of the approach in constructing process plans in a automated manner for common rotational / gear parts, the focus is on generating the operation. Gavankar [5] discusses the available methods of feature extraction and the classification of such features based on topology and geometrical attributes. Haddoc and Hartshorn [7] have discussed a scheme of specific machines selection

for machining a specific part dimension by correlating the part code and machine specification and qualification. The study of their proposal has been helpful in evolving the strategy for machine selection used in the present work.

1.4 PRESENT WORK AND ORGANIZATION OF THESIS

The present work attempts two levels of integration At one level the principles of production planning (Tersine [8]) are used to link the inputs of forecasting with CAPPS to evolve a comprehensive solution of the problem of machine selection, at the second level the some aspects of the current approaches to CAPPS have been integrated to evolve a workable system. The CAPPS in the current implementation combines certain features of the generative and variant schemes of process planning The idea of coding part and machine data and the use of part codes to narrow down the selection of machines to a certain subsection of the data base is borrowed from the procedure of constructing a process plan used in the "Variant Approach" to process planning. A important consequence of adapting this approach is that the of data base (Yao [9]), which is essentially organized in the relational model, is imagined as a data base having a hierarchical structure. The hierarchical view of data helps in devising a efficient search strategy, which is reflected in the heuristic used to make a preliminary selection of machines. This is, of course, an implicit assumption and does not translate into any visible features in the structure or the storage of the data base. As has been mentioned earlier in the discussion on generative process planning a comprehensive system for process planning using design information to construct a process plan for producing a component is difficult to devise. Accepting these limitations, the current implementation takes as input the complete list of part features in the sequence in which they are machined. A preliminary qualification of machines can

be made efficiently by using the information contained in the part code, the final selection is made from this list by considering the details of machine capability. In this manner the key features of the two accepted schemes of process planning are synthesized in the current implementation to evolve a rational and workable approach to CAPP. The emphasis of CAPP in the present work on providing a number of good alternatives from which a final selection can be made. Optimal solutions, in general, have not been targeted. The best among the alternatives can then be selected keeping in mind the balancing of machine loads and the previous experience of the management.

The problem and its central features have been introduced in the present chapter. The various principles and strategies that have been helpful in arriving at a solution have also been touched upon. Chapter II presents the system analysis and design. Chapter III discusses the details of the implementation. Chapter IV presents the results and discusses them in some detail. Chapter V presents the conclusions and the scope for future research.

CHAPTER II

SYSTEM ANALYSIS AND DESIGN

SYNOPSIS OF SYSTEM

The decision making system in focus in the present work is aimed at providing practical solutions to the problem of short listing machines required for the production of components of the products included MPS Starting with the demand of the products included in the MPS as input the system should be able to list all suitable machines for each of the operations required for the manufacture of the component parts in the decreasing order of their suitability.

The first step towards selecting suitable machines is the explosion of period wise product demand to the demand of component parts. This step requires the information on the product structures of all the different products. The next step towards the selection of machines is the listing of the operations required to produce each part A list of part features of each of the component parts is required for this purpose. Lastly the list of suitable machines is created by comparing the technological capability of the machines in the system with the operational requirements of the parts. For this all the relevant data about the available machines should be available to the system. As shown in Fig 2.1 these three steps of machine selection will require the inputs of three different subsystems. These three components of the system will interact with each other to process the inputs and to produce the final output.

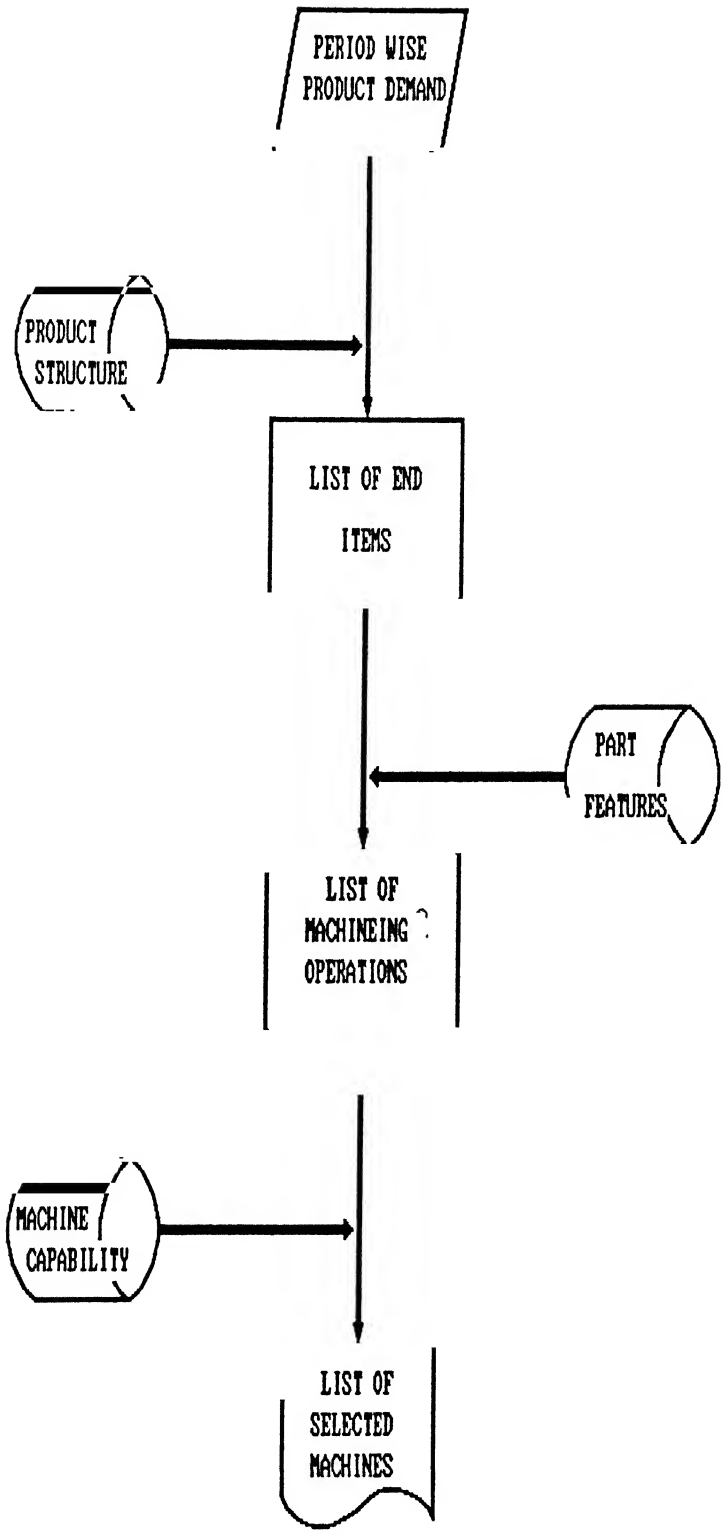


FIGURE 2.1 OUTLINE OF SYSTEM

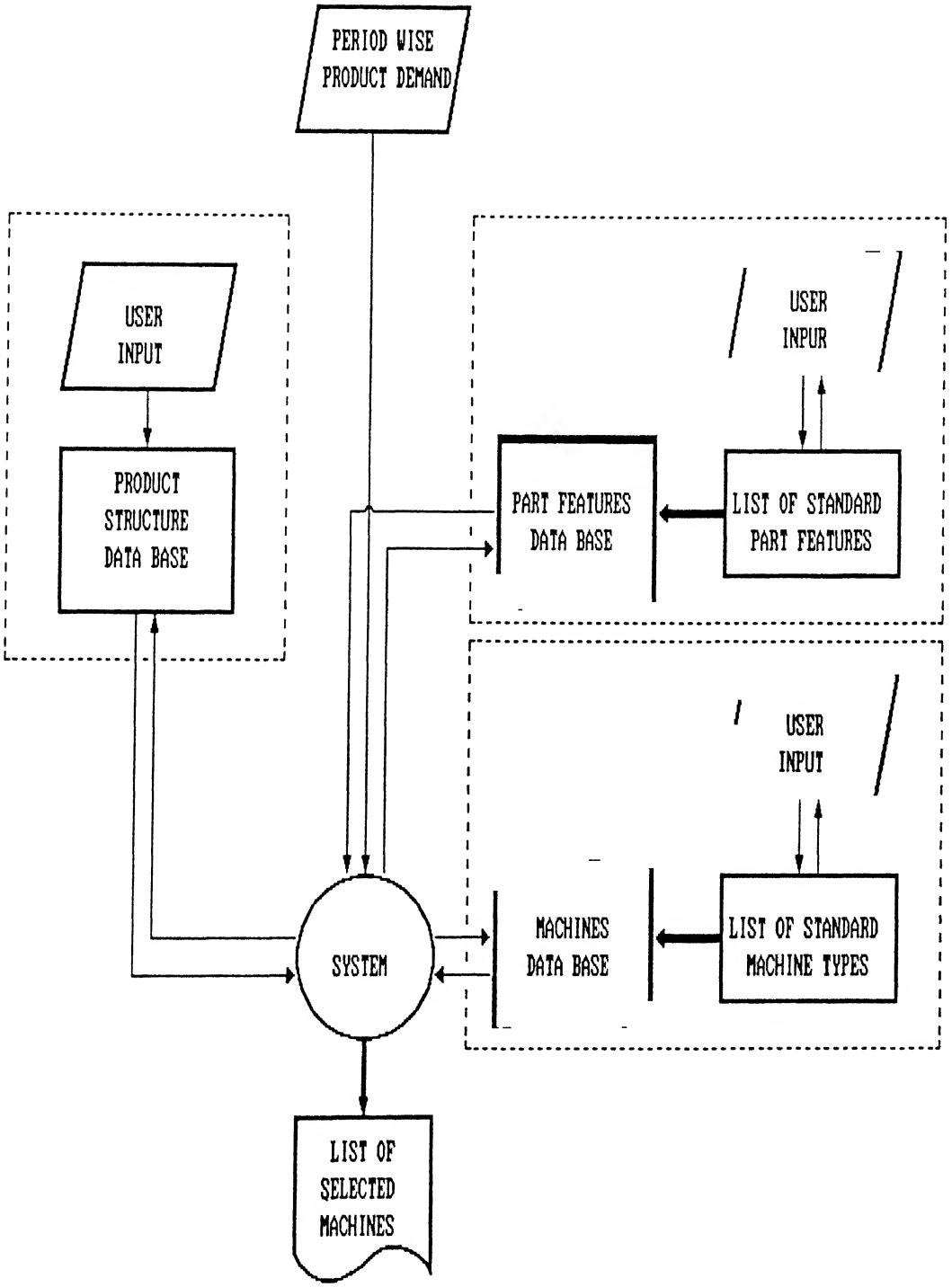


Figure 2.2 : Schematic Diagram of the Designed System

2.1 SYSTEM DESIGN

The system design can be divided into two broad categories (a) the core functional system, and (b) the supporting subsystems that perform the functions of creating and maintaining data bases that are accessed by the functional system The three components of the system that perform the three steps mentioned in the earlier section provide the main system with the relevant details on the product structure, part features and machine capability respectively In order to provide the required information the three components must maintain data bases on product structure, the part features, and machines capability (Fig 2.2) The data fields in the records of the data bases, the principles of their design and their utility will be discussed in the following section.

2.2 PRODUCT STRUCTURE DATA BASE

The bill of materials is an essential component of any production planning system as it contains information on the components that constitute the final product. This information is vital for the successful production of any product as well as for the synchronization of the timing of production of the components keeping in mind the due dates as well as the limitations of the production system in order to evolve an optimal production strategy In the present work the bill of materials file is obtained by processing the product structure data. The bill of materials is used to explode the period wise demand of finished products to that of the individual components that are to be manufactured. The demand of these components is the input to the CAPPS that is discussed in section 2.5. The organization of data in this file will be touched upon briefly. The product structure data can be visualized as having the a structure a inverted tree, the data structure used to store the product structure data goes by the same name. This organization helps in the efficient construction of the bill of materials of each

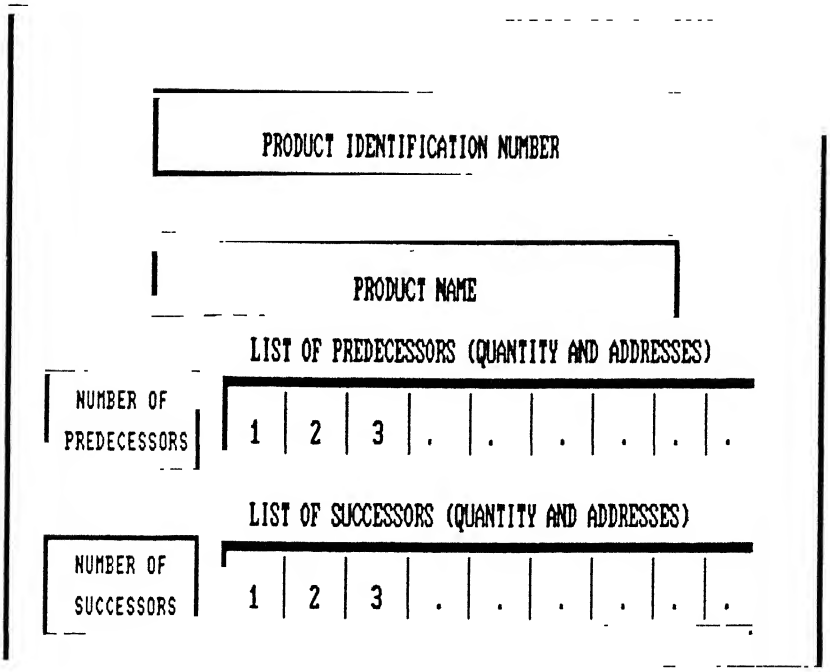


Figure 2.3 (a) : DATA STRUCTURE OF PRODUCT STRUCTURE DATA BASE

NAME OF FIELD	TYPE OF DATA STORED	SIZE OF FIELD	DISCRIPTION OF STORED DATA
PART IDENTIFICATION NUMBER	UNSIGNED LONG INTEGER	4 - BITES	THIS FIELD STORES THE PARTS IDENTIFICATION NUMBER
PART NAME	CHARACTER STRING	20 - BITES	THIS FIELD STORES THE PARTS NAME
NUMBER OF PREDECESSORS	UNSIGNED INTEGER	2 - BITES	THIS FIELD STORES THE NUMBER OF IMMEDIATE PEDECESSORS FOR THIS PARTICULAR PART
NUMBER OF SUCCESSORS	UNSIGNED INTEGER	2 - BITES	THIS FIELD STORES THE NUMBER OF IMMEDIATE SUCCESSORS FOR THIS PARTICULAR PART
LIST OF PREDECESSORS	ARRAY OF RECORDS	VARIABLE LENGTH	EACH RECORD OF THE ARRAY OF RECORDS STORES THE ADDRESS AND QUANTITY OF A PREDECESSOR
LIST OF SUCCESSORS	ARRAY OF RECORDS	VARIABLE LENGTH	EACH RECORD OF THE ARRAY OF RECORDS STORES THE ADDRESS AND QUANTITY OF A SUCCESSOR

Figure 2.3 (b) : DETAILS OF EACH DATA FIELD

product using the product structure data. The implementation provides for extensive validation of input data. It insures that,

(a) part identification numbers are not repeated, and

(b). no part has as an subassembly any item that is also its predecessor.

In addition, if two parts share one or more assembly the assembly is stored only once. Moreover the details of the subassembly are not required to be entered upon the second occurrence of the subassembly.

The product structure data is accessed by routines that;

(a) add a new product structure to existing file,

(b) modify a existing product structure by adding or deleting entries and,

(c) display the current status of any product structure in the file by allowing the user to browse through it

The sequence in which the entries are made in the product structure data base is as follows:

(a) the product identification number and product name is entered followed by the number of subassemblies in that product,

(b) the name and identification numbers of the subassemblies are then entered,

(c) the system then attempts to locate the details of the subassembly that was entered first, if the information is not available the name and identification number of the subassembly is displayed and the user is prompted to enter information on the immediate subassemblies of that subassembly. Similarly the next subassembly is processed.

This sequence of input ensures that all assemblies at the same level are entered one after the other. The system guides the user at each step of data entry in the product structure data base by providing help screens and by displaying relevant background information at each stage of input. Additions to existing

product structure are made in a similar manner, that is, the logical sequence of input operations is maintained. In the case of additions the product or assembly to which further subassemblies are being added is the starting point of input operations.

The details of the data structure used to store the product structure are shown in 2.3 (a) and 2.3 (b). Each record has the following data:

(a) The identification number.

(b) The product name.

(c) The number of immediate predecessors.

(d) The number of immediate successors.

(e) The complete list of the addresses of all immediate predecessors along with the number of units of the given component that will be required to manufacture one unit of a particular predecessor.

(f) The complete list of the addresses of all immediate successors along with the number of units of a particular successors that will be required to manufacture one unit of given product.

Clearly the bill of materials of all products and subassemblies can be easily obtained by processing the information available in the product structure data base. Further the data structure allows us to store data without any duplication, other than the fact that the predecessors list can be obtained by processing the subassemblies list. Providing both lists allows one to access the list of products that require a given subassembly in a more efficient manner. The facility of customizing the file reading and writing operations available in C^{++}, the chosen programming language allow convenient reading and writing of variable length records.

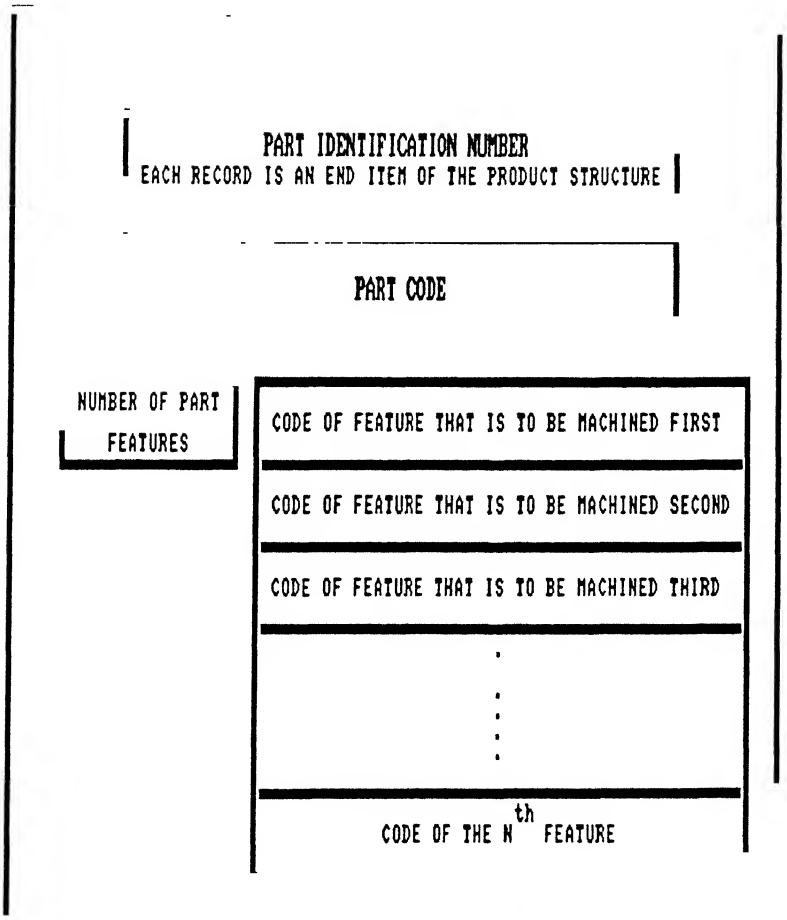
The bill of materials file obtained by processing the product structure is an essential input to CAPPS. The period wise demand of products is exploded using the bill of materials file to obtain the period wise demand of the end items that are actually manufactured.

2.3 PART FEATURES DATA BASE DESIGN

The parts data base has entries corresponding to each end component in the product structure data base. In accordance with this logical interrelationship the records in the parts data base have the same identification number as the corresponding entry in the product structure data base The other entries of the records of the part features data base include part code, the number of different part features and the codes of all the different part features. The data fields in each record of part features data base are shown in Fig 2.4.

2.3.1 CODING SCHEME

Two schemes are used in coding part data, the first scheme is used to code the part features. Part features, in the present work are defined as those geometric entities into which a parts internal and external surface can be classified, further it should be possible to machine these entities in a single machining operation. All form features are divided into four categories. Each of these categories are further divided into two sub categories namely internal form features and external form features which are further divided into specific forms. Classification of part features allows compact and meaningful coding of a large variety of part features. The part feature code records the category sub category and sub sub category of a particular part feature. The current implementation codes any given part feature in a 16-bit code the other 16-bits of the 32-bit code record the dimensions of the feature. These dimensions are recorded on a



RECORDS ARE OF VARIABLE LENGTH, THE ACTUAL LENGTH DEPENDS OF THE NUMBER OF DIFFERENT PART FEATERES THAT ARE PRESENT.

Figure 2.4 : DATA STRUCTIRE OF PART DATA BASE

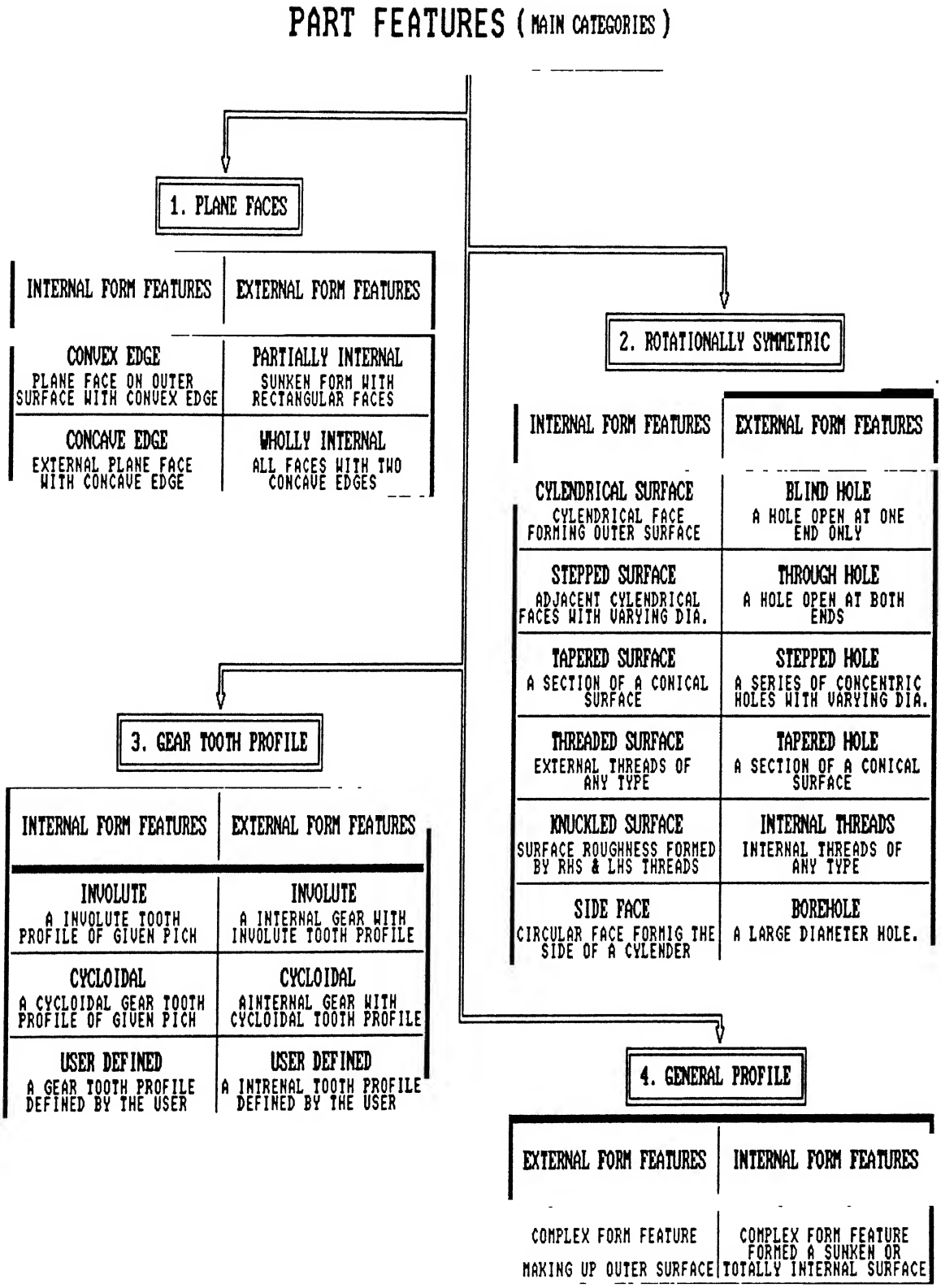


Figure 2.5 : PART FEATURES

logarithmic scale so that any dimension in the range of 1 mm to 5000 mm is scaled to a number between 0 to 255 which is then rounded to the nearest integer. The scaling procedure is such that the smaller dimensions are closer together while the larger dimensions are more widely spaced.

The other scheme condenses the information of all the coded part features in a particular part into a 8-bit code. To this code information on part material, surface finish requirement and the parts largest dimension is added to make the final 32-bit part code. The second scheme uses the codes that have been arrived at using the first coding scheme to form the first 8-bit section of the code. The method of coding the parts largest dimension that forms the last 8-bit section of the code is the same as that used in the first coding scheme. The code of material type and the level of surface finish is recorded as it is in the middle 16-bit section of the code.

The categories into which part features are divided, the sub categories of each category and the different features of each sub category are shown in Fig 2.5, they are:

(a) Features that are constituted of plane faces. Examples of such form features include all types of paralleopides, rectangular slots, T-slots etc.

(b) Rotationally symmetric form features such as cylindrical surfaces, bore holes tapered and stepped surfaces, threaded and knuckled surfaces etc.

(c) Gear teeth of standard (cycloidal and involute) and non standard profiles, both internal as well as external.

(d) General profiles, both internal and external which can not be broken into simpler components.

Each of these category of part feature is subdivided into internal and external form feature. So in order to unambiguously specify any particular part

feature one must specify its (a) category, (b) whether it is a internal or external feature and (c) its serial number in its own sub category. This is exactly how the part feature information is coded. The first 8-bit section of the code is reserved for specifying the category of the form feature, the next 8-bits are used to record the serial number of the part feature in its own sub category. The utility of this coding scheme will be discussed along with the method of selecting machines in section 2.5 since the utility of the coding scheme depends on how useful it is in short listing machines.

2.4 MACHINES DATA BASE

The records of the machines data base have fields for storing the machine identification number, the machine code and the details of all the different types of operations that a machine can perform.. As in the case of the product structure data base the machines data base has records of variable length, the exact length of a record depends on the number of different operations that a machine can perform.

All machines are divided into four basic types (a) Planer and Shaper, (b) Lathe, (c) Horizontal and Vertical Milling machine and (d) Drilling machine. Each type of machine can perform a number of different operations depending upon its flexibility and the number of different attachments that can be made to it. The machine code is designed to record all the different capabilities of the machine in the first 16-bit of the 32-bit code. It is therefore possible to list all the different capabilities of the machine by examining the first 16-bit section of the machine code. Since it is likely that the machine may perform the different operations that it is capable of with different efficiencies, it is necessary to record the data on machining efficiency for each operation separately. The data fields of the record of the machines data base have been designed by keeping these requirements in mind.

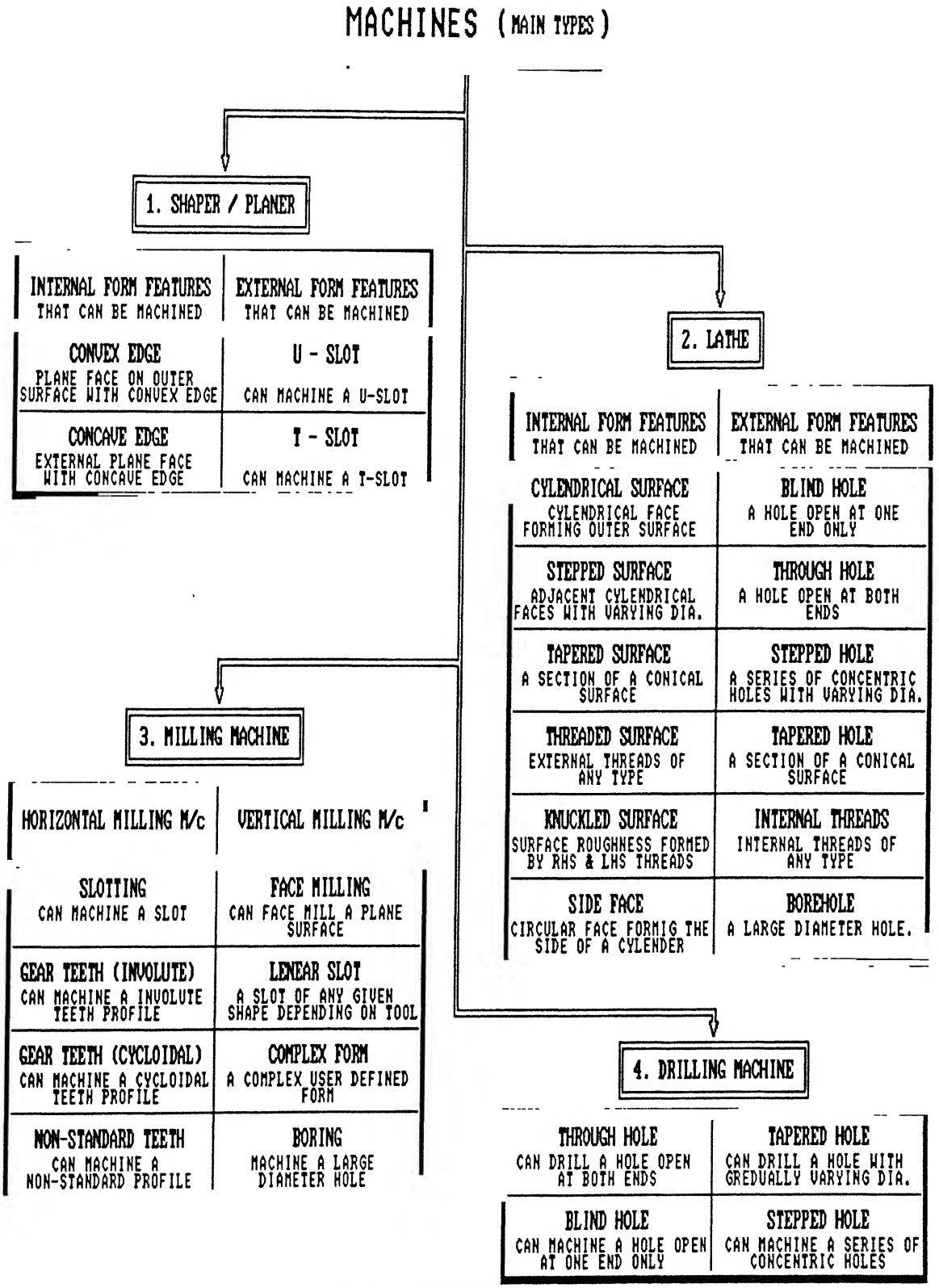


Figure 2.6 : CATEGORIES OF MACHINES

For comparing the different machines that are capable of performing a particular machining operation required for the production of a part some criterion for the evaluation of the relative advantages of different machines is required. The basis on which such a criterion is chosen is chosen can be, (a) the economy of operation or the (b) operational efficiency of the different operations. Of the two criterion listed above a manufacturing firm would choose the one that matches its priorities and world view. Since the present work seeks to focus on the operational aspects of the problem the criterion of operational efficiency will be assumed to be the dominant one. The rating of each of the available machine on the chosen measure of machine evaluation is therefore a important input in the process of selection of machines.

The different machines capable of performing a particular operation can be rated on the basis of the above mentioned criterion of machine evaluation. The code for recording the details of the machine capability is 32-bits long of which the first 16-bits specify the machines capability for performing one specific operation and the remaining 16-bits records the data on the machines rating for this particular operation. The first 4-bits of the 16-bit code used to record the details of the machine capability are used for storing the machine type, the remaining 12-bits are used for storing the serial number of a particular operation in its own category. Each one of the 12-bits is earmarked for recording whether the machine is capable of performing a particular operation. The final machine code is obtained by *'oring'* the bits of the first 16-bit section of the coded list of machine capability details. The design of the code insures that no information is lost in the oring operation. To this 16-bit code another 16-bits are appended. In these 16-bits the types of materials that the machine can deal with and the largest dimension of the parts that can be handled is coded.

The most significant bits of the code record the information on machine types from which it follows that the different types of machines can the grouped together by sorting machine data in increasing order of machine code. The fact that each bit of the machine code records a particular piece of information makes it possible to pick all machines having any given characteristic efficiently. For example all lathes that have boring attachments, can machine materials of type 1 and type 4 and can machine parts with length 1000mm can be found by designing a suitable template and *'anding'* the machine codes iteratively with this template, each time a non-zero result would indicate that the current machine fits the description.

The types of machines and the operations that each type of machine can perform is shown in Fig 2.6. As in the case of the parts data base discussed in earlier section the categorization of all machines into different types allows the compact coding of machine data. The other advantage of the present coding scheme is that it is similar to the coding scheme of the part data base, as a result the method of entering data in both data bases are very similar this reduces the effort on the part of the user to learn this operation.

2.5 MACHINE SELECTION

The process of machine selection starts with the user demand of products in one period. This demand is exploded using the bill of materials file to the obtain the period wise demand of end components (Fig 2.7). Using the part identification number as key the corresponding record in the part features data base is located.

The next step in the automated generation of a process plan is to find the list of machines suitable for the each step in the machining sequence required to produce each part. Each record of the part features data base contains the entire

MACHINE SELECTION

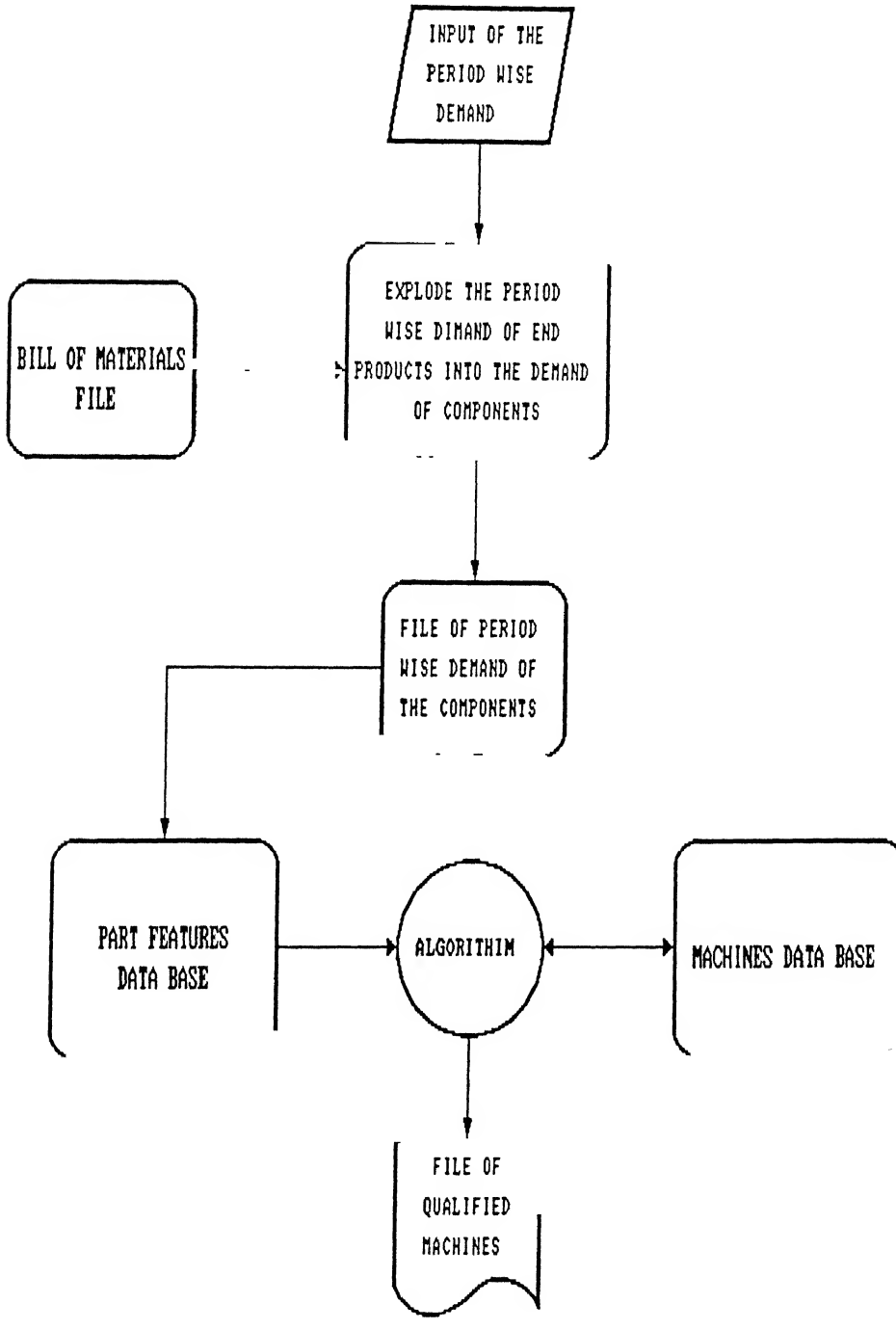


Figure 2.7 : Outline of the Procedure of Machine Selection

list of part features that are to be machined. This list is ordered in the sequence in which those part features have to be machined. For the generation of the process plan suitable machines have to be located from the machines data base. This step requires the processing of the part feature code and the generation of a set of templates which will help in short listing the suitable machines.

Machine selection uses a "*correlation data*" file in which the templates required to isolated qualifies machines are listed against the part features code. The first 16-bits of the part features code that specify the part feature are isolated. Next the entries in the correlation data file corresponding to this part feature code are read iteratively. Each of these templates is used to pick a list of probable machines from the machine data base. This list is further pruned using the information on material type and the part's largest dimension which are recorded in the last 16-bit section of the part code. The selected machines are then sorted on the basis of the machining time data. This list of machines is the final list of qualified machines with the most suitable machines at the head of the list and the less suitable ones towards the tail end of the list.

The procedure of machine selection is able to isolate records from the machine data base essentially because the relevant information about the machine capability is available in the machine code. Further the different operations that the machine is capable of do not have to be listed explicitly to check whether the machine is capable of a particular operation. In other words without actually analyzing the machine code the suitability of a machine for performing a particular operation can be gauged simply by '*anding*' the machine code with a suitable template.

2.6 CODING IN AN OBJECT ORIENTED LANGUAGE

Borland C++, a language that includes object oriented features, is used as the programming language. Object orientation provides a fresh approach to programming problems which differs from that of procedural languages. In procedural languages the problem is broken up into independent parts which are then integrated This approach, known as the top down approach, makes the task of analysis difficult and cumbersome. The object oriented approach, known as the bottoms up approach, on the other hand, allows us to model entities in a manner that mimics their real world behavior this simplifies the analysis and aids our thinking in arriving at a final solution (Ezzel [10])

A object oriented language has the in built discipline of allowing only member functions access to the private and protected data of each record. Other routines can access and manipulate the private and protected data only through the member functions. Due thought must be given not only in deciding the data fields that must be present in each record but also to the types of operations that are to be performed on the data. These operations, called the class method, together with the data fields are known as classes. Once the class methods have been defined, the programmer, in effect, provides himself a higher level interface. The other advantages of object orientation are (Borland C++ [11]):

(a) It lends structure to the solution by providing selective access to data.

(b) Since larger program are necessarily constructed from smaller, well tested blocks debugging of large projects is easier.

Borland C++ provides a useful class library which includes all the commonly used data structures like stacks, queues, set etc. The common operations performed on these data structures are predefined in the class library. These data structures are used extensively in the current implementation. The use

of the data structures available in the class libraries makes the code fairly compact, this is one of the advantages of using a object oriented language.

CHAPTER III

SYSTEM IMPLEMENTATION

3.1 OUTLINE OF IMPLEMENTATION

The implementation is designed to be an interactive application, in which all the functions of the system are accessed through a set of menus and sub menus The user is helped in navigating the menu structure by the provision of relevant help messages at the bottom of the screen and in special help windows in the cases where detailed instructions were considered necessary All the operations that are performed on each of the three data bases are grouped together in the menu structure The records of the part features data base which has a one to one correspondence with the end components of the product structure data base are created and accessed via the corresponding entries in the product structure data base. An attempt has been made to give the user a intuitive feel of the structure and the organization of the data bases and the relations that exist between the various data bases by the design of the menu structure and by the method of entering of information. It s for this reason that the implementation features will be discussed by tracing the menus structure.

The main menu has five items; **parts, machines, bill of materials, process plan** and **quit,** which allows the user to exit from the system. The sub menus corresponding to each of these entries are listed in the following table.

(1) PART	(a) Product structure data base.
	(b) Part features data base.
(2) MACHINES	(a) Add / edit / delete machine capability data.
(3) BILL OF MATERIALS	(a) Construct bill of materials.
	(b) View the bill of materials.
(4) PROCESS PLAN	(a) Construct demand list.
	(b) Modify demand list.
	(c) Select from demand files.
	(d) View demand file.
	(e) Construct process plan.
	(f) View process plan.

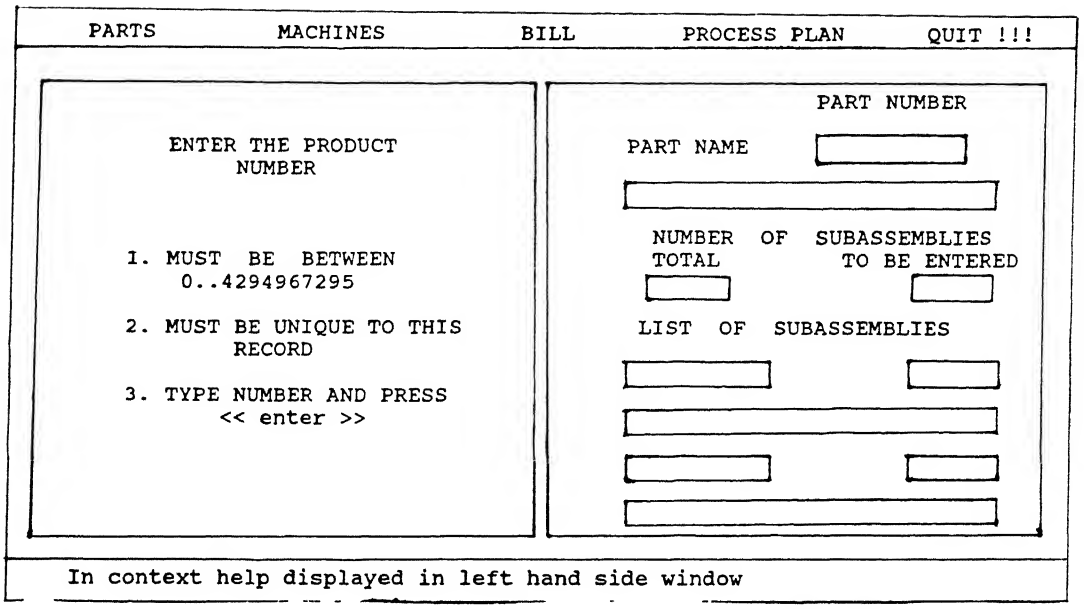
The operation / sub menus accessed by each of these items will be discussed in the following sections. Operations corresponding to item 4 will be discussed before item 3 for the sake of clarity.

3.2 PRODUCT STRUCTURE DATA BASE

Evoking this menu item opens a sub menu which allows the user to select among the following entries.

3.2.1 CONSTRUCT NEW PRODUCT STRUCTURE

Evoking this item allow the user to construct a new product structure. The user is prompted to enter the identification number of the product. The limit



Figire 3.1 : Identification Number Help Screen

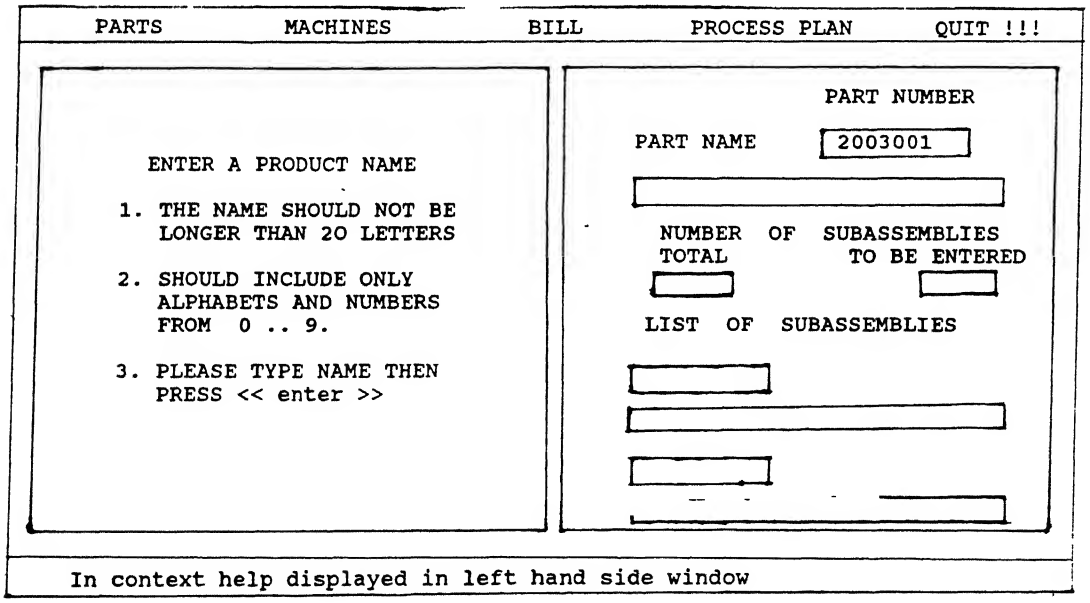


Figure 3.2 : Part Name Help Screen

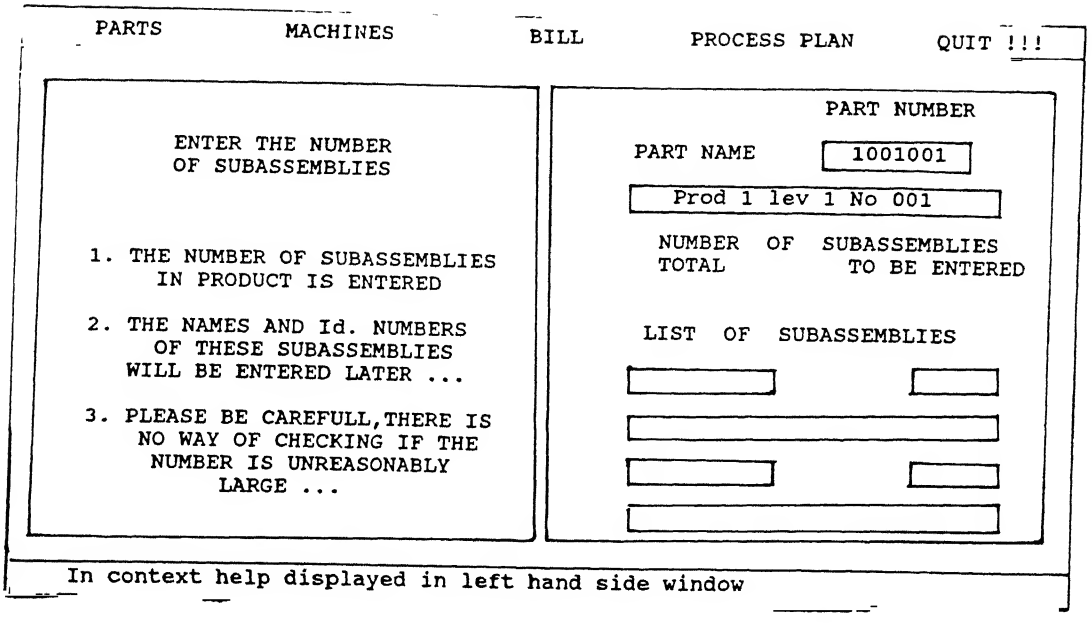


Figure 3.3 : Print Screen for the Entry of Subassembly Number

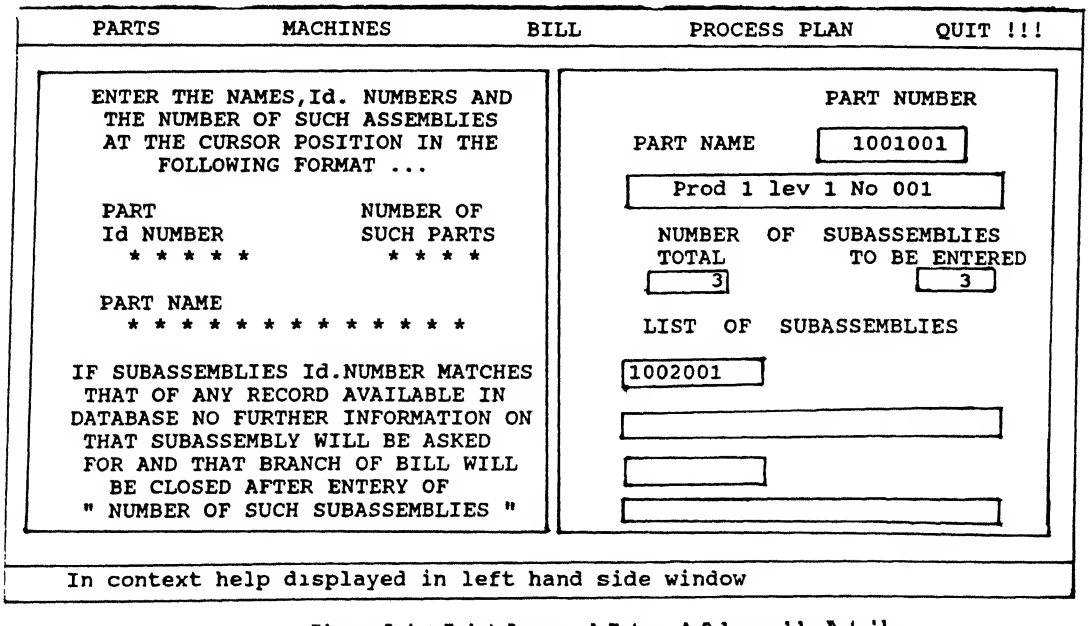


Figure 3.4 : Print Screen of Entry of Subassembly Details

on the size of the identification number and other help information are displayed in a window on the left hand side of the screen (Fig 3.1). The system insures that the identification number is unique by rejecting repetitions and prompting the user to renter the identification number. Next the system asks the user to enter the product name (Fig 3.2). The relevant help is displayed in the help window. By a procedure similar to that used in the case of the part's identification number the system insures that the part name is unique. The system then prompts the user to enter the number of immediate subassemblies(Fig 3.3). Once the number of subassemblies has been entered the system asks the user for the identification number and name of each of these subassemblies, if the identification number of the subassembly is the same as that of any other record excluding that of its predecessors, the system automatically accesses all the necessary information and displays it on the screen. No further details are required for this entry (Fig 3.4). Once all the subassemblies have been entered the subassembly that was entered first is displayed and the system prompts the user to enter further details on this subassembly in a manner which is exactly similar to the way in which the subassemblies of the product were entered. The system keeps track of all the subassemblies whose details have not been entered. The details of the subassemblies that are at the same level in the product structure are asked for one after another, the system therefore reads the items of the product structure in a **'breadth first'** manner. The **'breadth first'** method of scanning a tree is more memory intensive but it offers greater convenience to the user.

3.2.2 ADD SUCCESSORS TO PRODUCT STRUCTURE

Evoking this menu item displays a help screen that instructs the user on the procedure by which he can chose the product structure as well as the precise location in the product structure where he wishes to insert further subassemblies (Fig 3.5). The user has the option of indicating the location where further

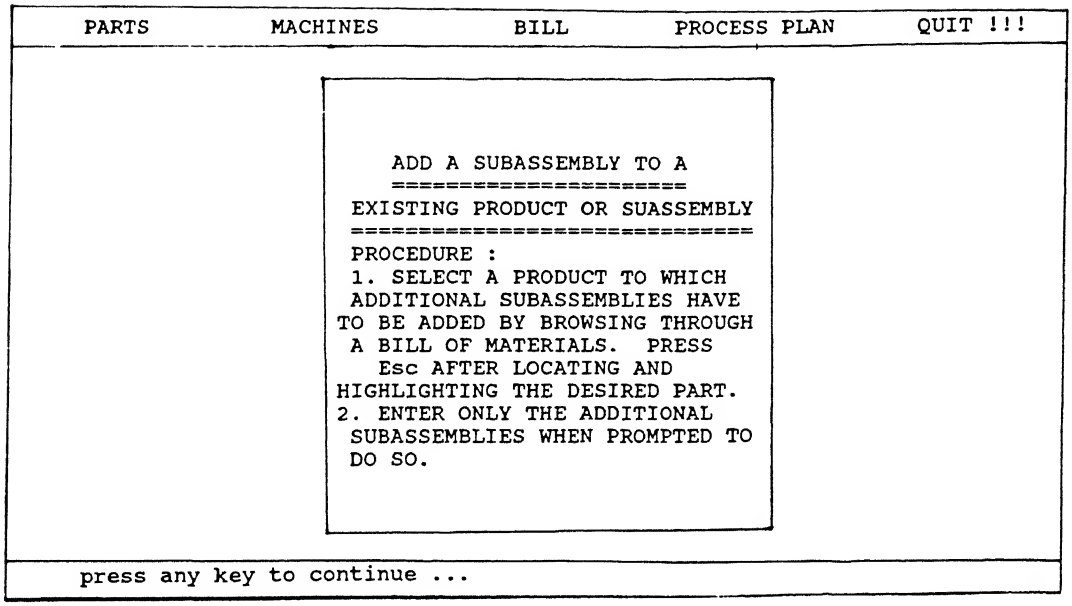


Figure 3.5 : Help Screen for Adding Subassemblies to Product

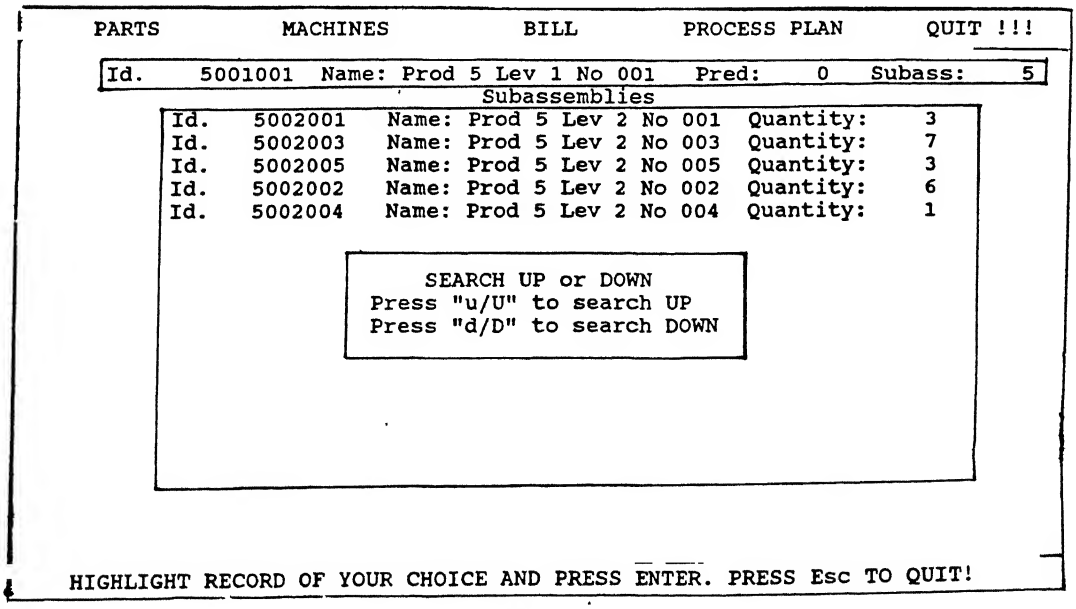


Figure 3.6 : Print Screen of Traversal of Product Structure

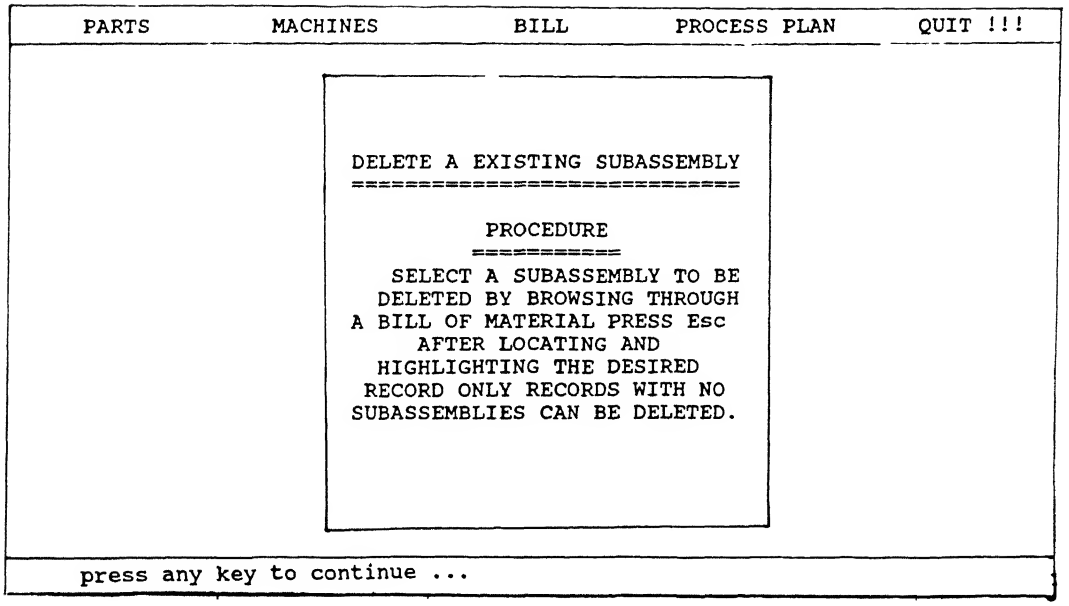


Figure 3.7 : Help Screen for Deleting Subassemblies from Product

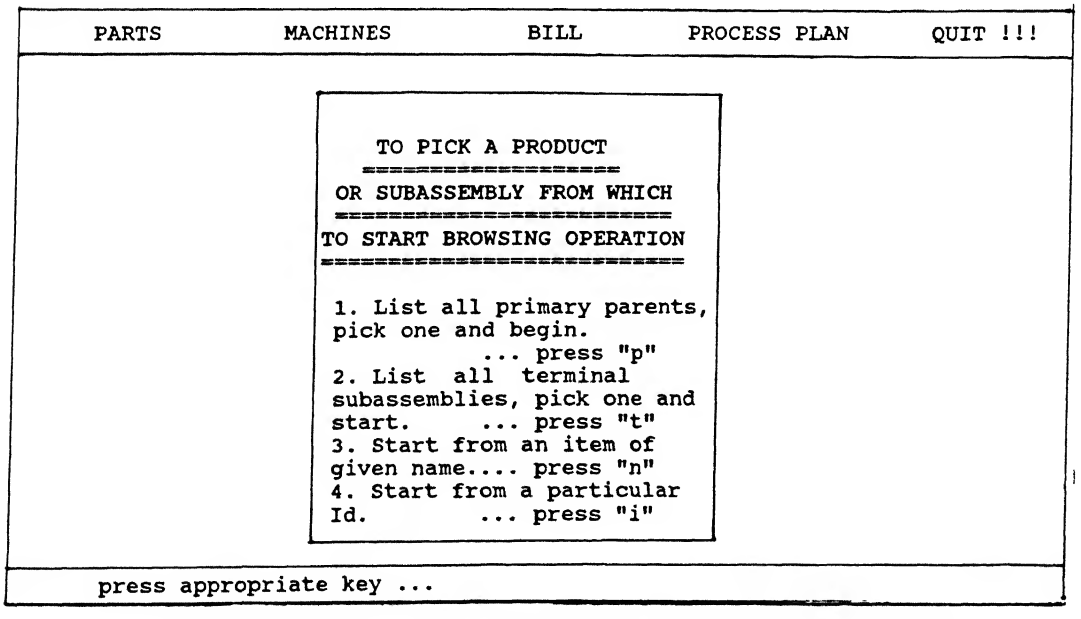


Figure 3.8 : Print Screen of Methods of Choosing Starting Point for Traversal

subassemblies have to be added by typing (1) the product name, (2) the product identification number, (3) by choosing from the list of products and (4) by choosing from the list of end components. In case the user selects option (3) or (4) he can browse through the product structure either upwards on downwards. He does so by high lighting the item of his choice, the system then prompts the user to indicate whether he wishes to traverse up or down the product structure (Fig 3.6) Depending upon the choice the system lists the immediate predecessors or successors of that particular item. After the user has indicated his choice the system displays the user's choice of the item to which successors have to be added. The user is asked to enter the number of additional successors that are to be added. The subsequent procedure of data entry is similar to the procedure of creation of a new product structure that is described in the earlier paragraph.

3.2.3 DELETE SUBASSEMBLIES

This choice allows the user to delete end components from a product structure one at a time. Choosing this option displays a help screen (Fig 3.7) on the method of choosing the end component to be deleted, as in the case of adding more subassemblies the user is provided four methods of indicating his choice of item to be deleted. One the user has made his choice the system cross checks to ascertain whether the indicated item is actually a end component before it is delete from the data base.

3.2.4 VIEW PRODUCT STRUCTURE

This item allows the user to browse through the product structure of any product in the data base. Selecting this option displays (Fig 3.8) four options; these are:

(1) select by name,

(2) select by identification number,

(3) select from the product list and

(4) select from end item list.

The first two options are self explanatory, selection of these option displays the chosen item at the top of the screen followed by the list of its successors, in case the item is an end item and has no further successors the list of predecessors is displayed. In the case of option 3 the list of product is displayed and in the case of option 4 the list of end components is displayed. The user can select a item from this list, next he is prompted to indicate whether he wishes to move up or down the product structure. If it is not feasible to move in the indicated direction, for example if the list of further subassemblies are asked in case of an end component the system will display the list of its parents from which the user can infer that it is an end item.

3.2.5 PART FEATURES

As mentioned earlier the records of the part features data base have a one to one correspondence with the end components of the product structure data base. This fact is exploited in the design of the method of adding and updating the records of this data base.

Each time a new product is added to the product structure data base or an existing product structure is modified to add new subassemblies, a corresponding entry must be made in the part features data base. Similarly when a product structure is deleted or a existing structure modified by deleting certain successors the entry corresponding to the deleted end items become unnecessary and must be deleted. In case the part features data base is not updated immediately upon the addition of new end components in the product structure data base, the

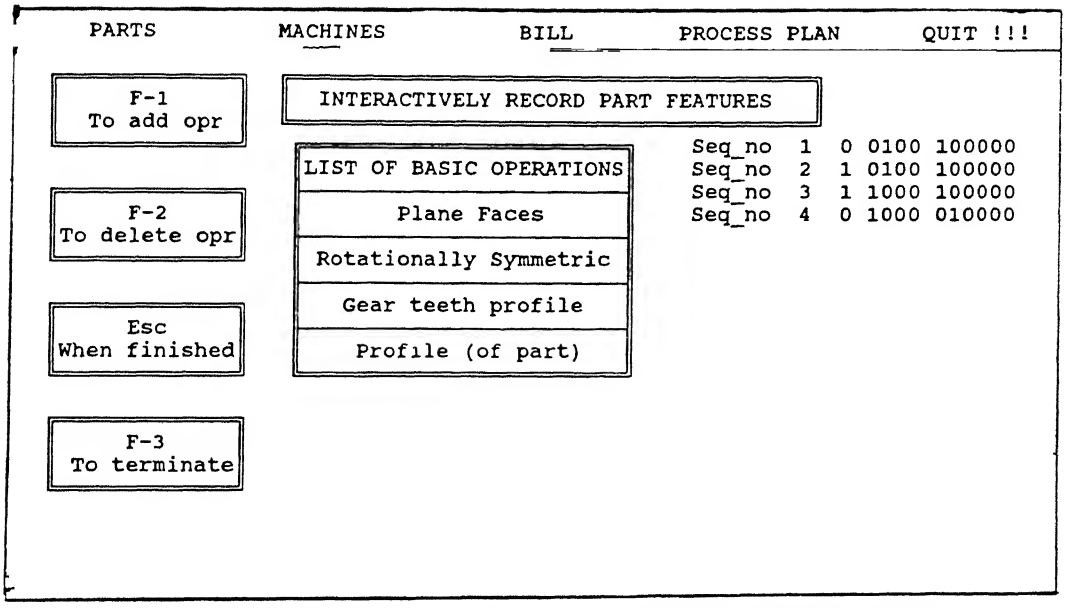


Figure 3.9 : Print Screen of First Screen of "Add/Edit Part Features Data"

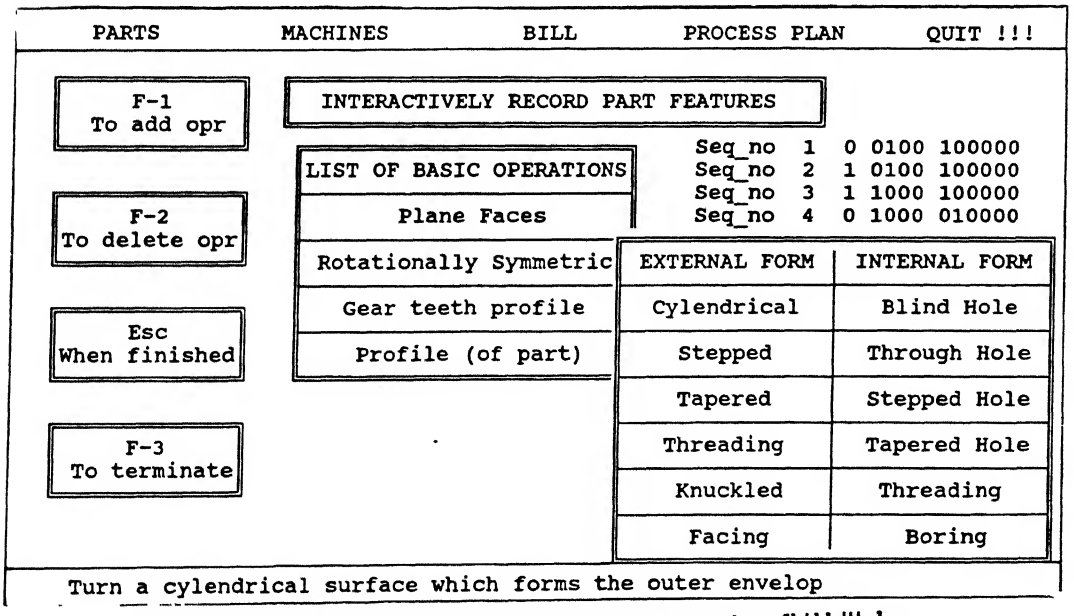


Figure 3.10 : "Add/Edit Part Features Data" Screen With a Open Child Window

list of end components for which there is no corresponding entry in the part features data base keeps growing. These end components are treated in a different manner from those for which the part features list is already available.

The user can choose whether he wishes to edit the part features list of an existing record or wishes to add a new record to the part features data base. In either case the list of end components that the user can choose from is displayed. The user can scroll through the list and choose any particular record. Internally the system processes the records of the product structure data base and makes a list of all end components. For each end component the system attempts to locate a corresponding entry in the part features data base and depending on the result of this search, the part is either added to the list of records for which there is no corresponding entry in the parts features data base or to the list of end components for which a entry is available. Once a record is chosen, the list of coded part features that have been already entered is displayed. The user can scroll through the list and delete any part feature or he can choose the position in the list where he wishes to add a new part feature (Fig 3.9). To add a new part the user chooses from the list of the categories of part features that is displayed, depending upon his choice a child window listing all the part features is displayed (Fig 3.10). Any of these features can be selected by the user. The system then automatically prompts the user to enter the dimensions of the part feature. When all the data corresponding to a particular part feature has been entered the part feature is added to the list at the position that has been indicated by the user.

The process may be repeated to add another part feature. When the user indicates to the system that all the part features have been entered the system prompts the user to choose the material type of the part, followed by the surface finish requirements and the largest dimension of the part. The system insures that

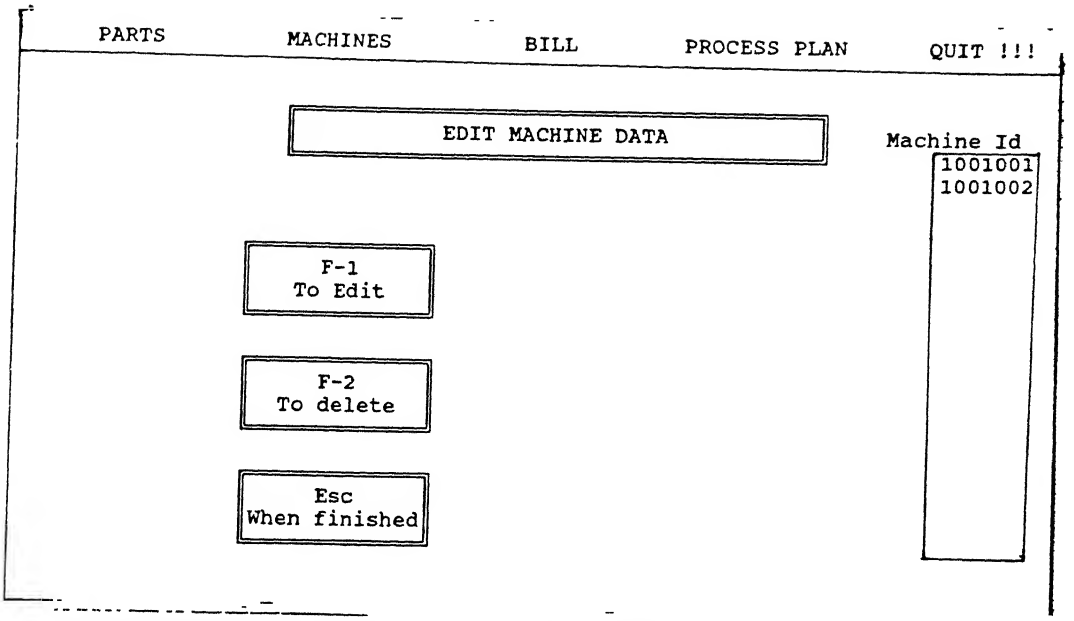


Figure 3.11 : Print Screen for Choosing/Adding Machine for Deletion/Editing/Creation of Machine Capability Records

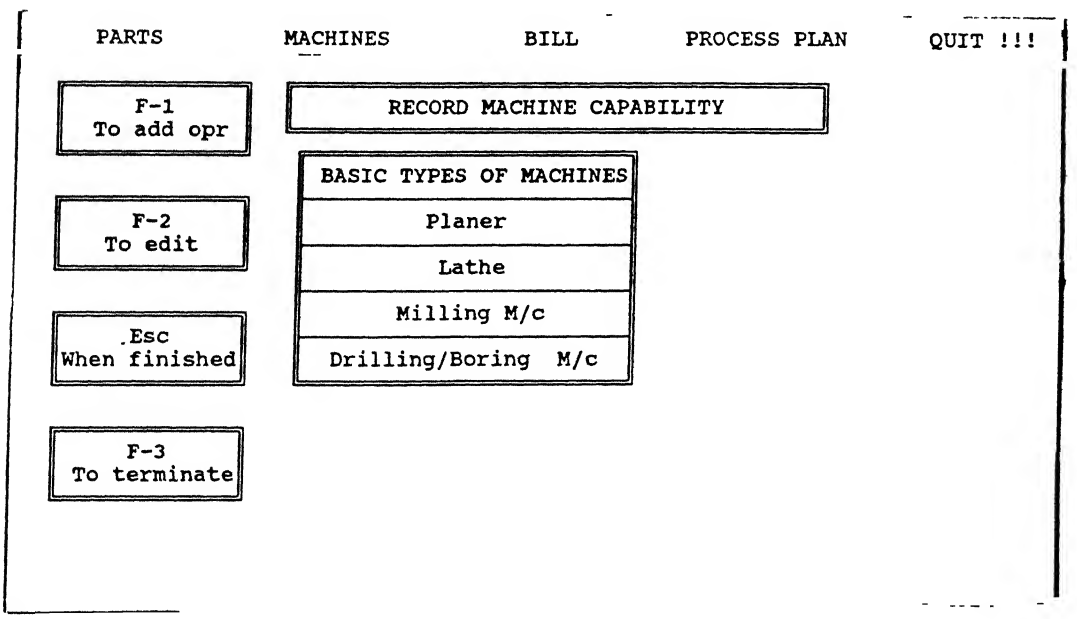


Figure 3.12 : Print Screen of First Screen of "Add/Edit/View Machine Capability Data"

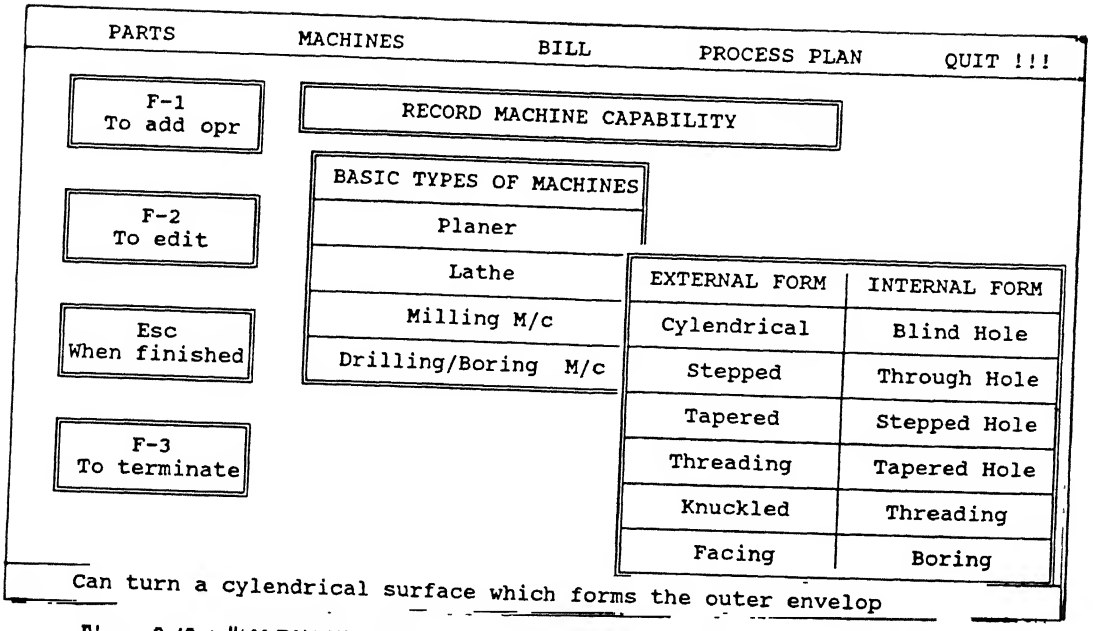


Figure 3.13 : "Add/Edit/View Machine Capability Data" Screen With a Open Child Window

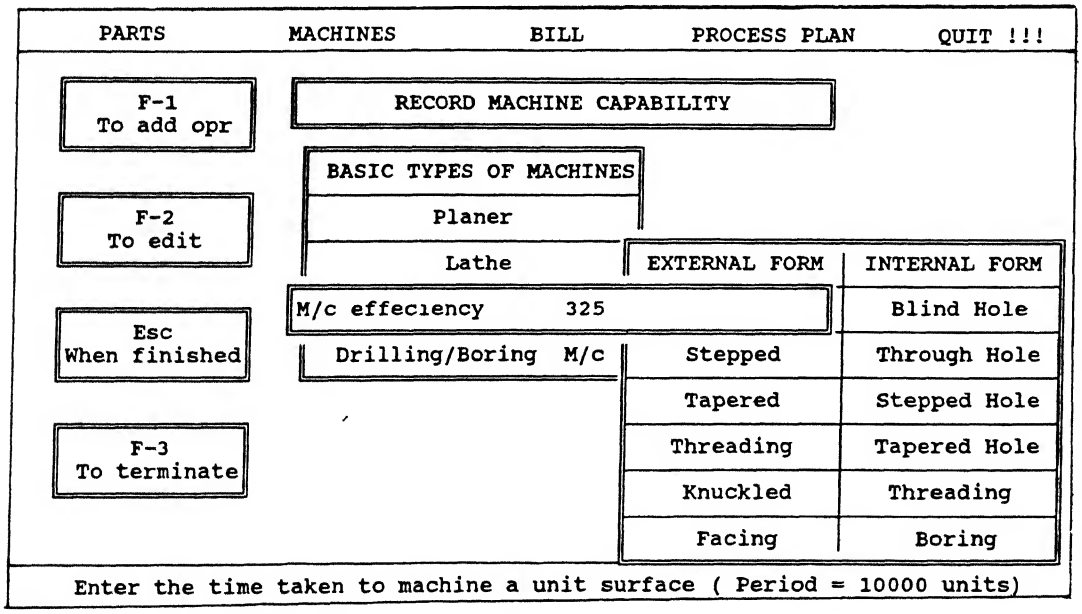


Figure 3.14 : Print Sreen of Entry of Machine Rating

the largest dimension of the part is larger than all the dimensions corresponding in the part features list.

3.3 MACHINES

On selecting this option the system displays the list of machine identification numbers in a window on the right hand side of the screen. On the left hand side of the screen three buttons that are activated by the function keys are displayed (Fig 3.11). The three buttons perform the operations of (1) **'add to the list / edit / view machine capability data'** (2) **'deleting from the list'** and (3) **'save changes and exit to main menu'**. The user can scroll through the list of machines and delete any of the existing machines, or he can activate the first button to edit or view a record. To add more machines the user scrolls to the bottom of the list and activates the **'add to the list / edit / view machine capability data'** button. A window appears in the middle of the screen and the user is prompted to enter the identification number of the new machine. The system then checks the identification numbers of other records in the data base to establish whether the identification number is unique. In case it is not unique the user is asked to enter another identification number otherwise the system goes over to the **'add to the list / edit / view machine capability data'** screen (Fig 3.12). To the left side of the screen are the buttons that perform the operations of (1) entering data in a new record or entering data in a old record afresh, (2) viewing or editing the data of a previously created record and, (3) ending the editing operation, closing the current record and returning to the previous screen. The middle of the screen has a window listing all the basic machine types available. The user can highlight any of these machine types and activate button 1 to open a child window listing the different operations that the machine is capable of performing. Next he can choose any of the displayed operations (Fig 3.13). A window opens at the center of the screen and the user is prompted to enter the data of machine rating (Fig 3.14). The

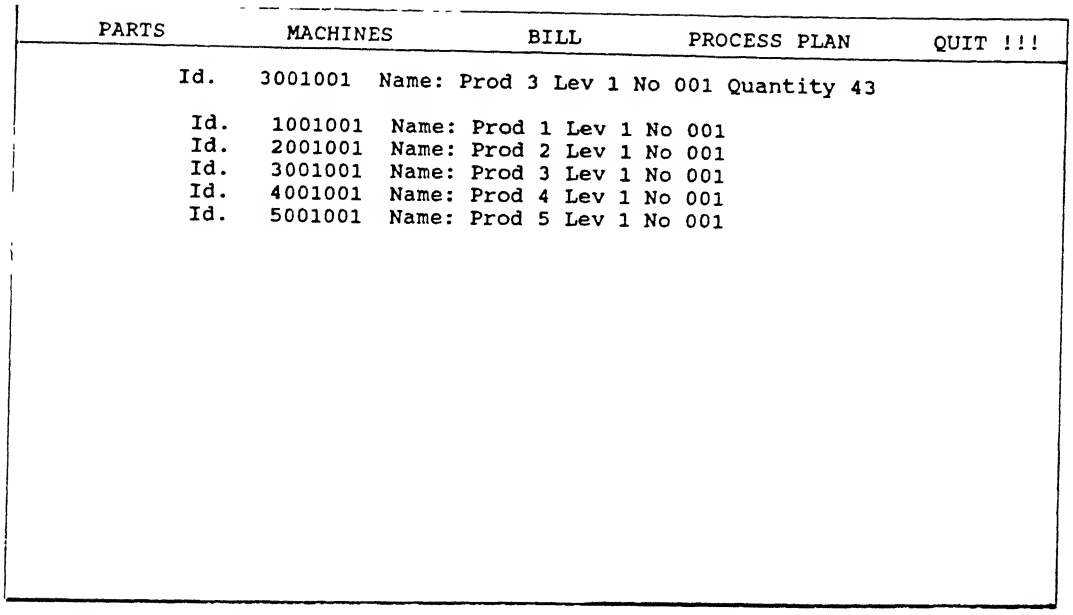


Figure 3.15 : Print Screen Operation of Recording Period Wise Demand

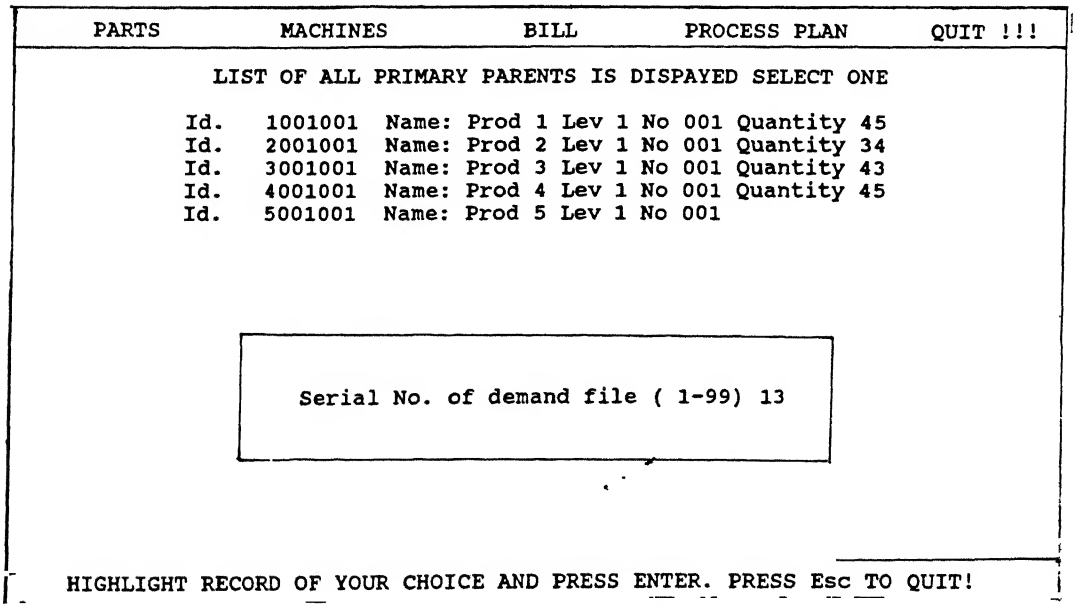


Figure 3.16 : Print Screen of the Operation of Assigning a Serial Number to Demand File

system then closes the window and the next operation that the machine is capable of performing can be recorded. The operation that was recorded earlier remains high lighted so the user has no difficulty in keeping track of the operations that he has already entered. The user can delete any of the operations entered earlier by toggling the high light of the operation that he wishes to delete. To view a existing record the user activates button 2. This automatically open the relevant child window and high lights the operations that the machine is capable of performing. The editing of this record proceeds in a manner exactly similar to the method of creation of a new record described earlier. Finally to quit editing the record the user activates button 3. He can alter the information in the record at this stage by pressing button 1 or button 2. The user can end the current operation by activating button 4. The system then prompts the user to enter data on the types of materials that the machine can handle and the largest dimension of the part that it can handle. It is clear that the set of operation that are provided by the system can handle any type of manipulation of records that the user may wish to perform.

3.4 CONSTRUCT A DEMAND LIST

The procedure of constructing a new demand file is activated by this menu item. The list of all the products is accessed by this procedure and displayed in a window at the center of the screen the user can scroll through this list and choose any product. The chosen product is displayed at the top of the screen and the user is asked to enter the demand for the item (Fig 3.15). Once the demand has been entered it is added to the end of the line in which the product name and identification number are displayed. Finally when the complete demand list has been registered the user is asked to enter the serial no of the new file (Fig 3.16). Any number between 1 and 99 would be valid entry. This means that up to 99 demand files can be created. This is also made the active file which means that of

all the demand files existing at that point of time this particular file will be accessed by the routines that construct the bill of materials and the process plan.

3.4.1 MODIFY DEMAND LIST

This menu item allows the user to alter the contents of the active demand file. The procedure followed is the same as that followed in creating a fresh demand file. The user selects the products one by one and enters the demand for each product. The difference between the procedures is that the user is not asked to enter the serial no of the demand file as this is already known to the system.

3.4.2 SELECT FROM DEMAND FILES

The operation accessed by this menu item allows the user to make any of the previously entered demand files the active demand file. All the demand files that have been previously entered are displayed in a window on the screen the user can pick any of these files. The chosen file becomes the active demand file, which means the routines that construct the bill of materials and the routines that make the final process plan will access this file.

3.4.3 VIEW DEMAND FILE

The active demand file can by viewed from within the system by this menu item. A window is created in the middle of the screen and the active demand file is displayed. In case the demand file is too long to be displayed in one screen the user can scroll through the file and view its contents.

3.4.4 CONSTRUCT PROCESS PLAN

On selecting this menu item the process plan for the production of end components that will be required for the assembly of products listed in the active demand file will be made The system will first check the part features data base for completeness, because the completeness this data base is essential for the successful construction of a process plan. In case it is not complete a message to this affect will be displayed

3.4.5 VIEW PROCESS PLAN

Evoking this menu item allows the user to view the final output of the system. The output is in the form of a text file, the demand of each end component is listed along with the list of machines suitable for performing these operations. The selected machines are listed in the decreasing order of their suitability for performing that particular operation. The list has a maximum length of 5. This length can be altered by making very minor changes in the file "PROCESS.CPP".

3.5 CONSTRUCT BILL OF MATERIALS

This procedure constructs the bill of materials file for the products listed in the active demand file. This is an additional facility provided by the system, it allows the user to find out the quantities in which the end components will have to be produced to honor the current demand list. The output of this procedure is not visible on the screen. It is recorded in the file "BILL_MAT.DAT."

3.5.1 VIEW THE BILL OF MATERIALS

Evoking this menu item displays the bill of materials that was last constructed. The user is shown the file "BILL_MAT.DAT." from within the system. If the entire file does not fit in the window, as is usually the case, the user can scroll through the file and view all parts of the file.

3.6 PROGRAM FILES AND PROGRAMMING FEATURES

The implementation has the following header files:

(1) MENUS.H : Contains the definitions of the classes used in the menu system.

(2) DATADEFS.H: Contains the definitions of the data structure, the classes used in the product structure data files and the prototypes of the most commonly used functions.

(3) PARTMACH.H : Contains the definitions of the data structure, the classes used in the part features and machine capability data bases and the prototypes of the most commonly used functions.

The program files are grouped together under three projects the **display project**, the **product structure project** and the **part machine project**. The program files under each of these projects are:

Display project :

(1) DISPLAY.CPP : Displays the output of programs.

(2) MENUS.CPP : Definitions of the member functions of the classes defined in MENUS.H.

(3) DATADEFS.CPP : Definitions of the member functions of the classes defines in DATADEFS.H

(4) COMPROC.CPP : Definitions of frequently used routines.

Product structure project :

(1) MAIN_BILL.CPP : Regulates the passing of controls to the different procedures under this project file.

(2) BILL_MRK.CPP : Routines for reading and writing product structure information as well as the engine for creation and update of this data base.

(3) MANIP_BL.CPP : Routines for initializing the editing operations of the product structure.

(4) BROWSER.CPP : Routines for allowing the user to browse through the product structure.

(5) MENUS.CPP : Definitions of the member functions of the classes defined in MENUS.H.

(6) DATADEFS.CPP : Definitions of the member functions of the classes defines in DATADEFS.H

(7) COMPROC.CPP : Definitions of frequently used routines.

Part machine project :

(1) PAMCMAIN.CPP: Regulates the passing of controls to the different procedures under this project file.

(2) PROCESS.CPP : Routines for constructing the bill of materials and the process plan.

(3) MACHINES.CPP : Definitions of the member functions of the class PART_MC.H.

(4) PARTS.CPP : Definitions of the member functions of the class PART_MC.H.

(5) MENUS.CPP : Definitions of the member functions of the classes defined in MENUS.H.

(6) DATADEFS.CPP : Definitions of the member functions of the classes defines in DATADEFS.H.

(7) COMPROC.CPP : Definitions of frequently used routines.

The program file "THESIS.CPP" controls the menu structure and passes control to the other projects depending upon the menu item chosen. The program structure is flexible, modifications and extensions can be made without affecting the basic structure.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 INPUTS TO THE SYSTEM

The results obtained with the designed system for different inputs form the basis for the evaluation of system behavior. The principal inputs to the system are the entries in the three data bases discussed in section 2.2, they are (a) the product structure data base, (b) the part features data base, and (c) the machine data base. The product structures that form the inputs to the system are shown in Fig 4.1 (a), (b), (c), (d) and (e). The end components corresponding to these data bases are shown in Fig 4.2 (a) to Fig 4.6 (g). The machines of the machine data base are shown in Fig 4.7 (a) to Fig 4.7 (r).

The following demand file .is entered into the system

Id. 1001001 Name: Prod 1 lev 1 no 001 Quantity 2
Id. 2001001 Name: Prod 2 lev 1 no 001 Quantity 3
Id. 3001001 Name: Prod 3 lev 1 no 001 Quantity 1
Id. 4001001 Name: Prod 4 lev 1 no 001 Quantity 5
Id. 5001001 Name: Prod 5 lev 1 no 001 Quantity 7

All the products in the data base are included in this file.

4.2 BILL OF MATERIALS

The bill of materials file generated by the system is reproduced below.

Part Id 1001001 Part Name Prod 1 lev 1 no 001
Level 0 Quantity 1
Has further subassemblies:
Part Id 1002001 Part Name Prod 1 lev 2 no 001
Part Id 1002002 Part Name Prod 1 lev 2 no 002
Part Id 1002003 Part Name Prod 1 lev 2 no 003

Part Id 1002001 Part Name Prod 1 lev 2 no 001
Level 1 Quantity 3 Is an end item.

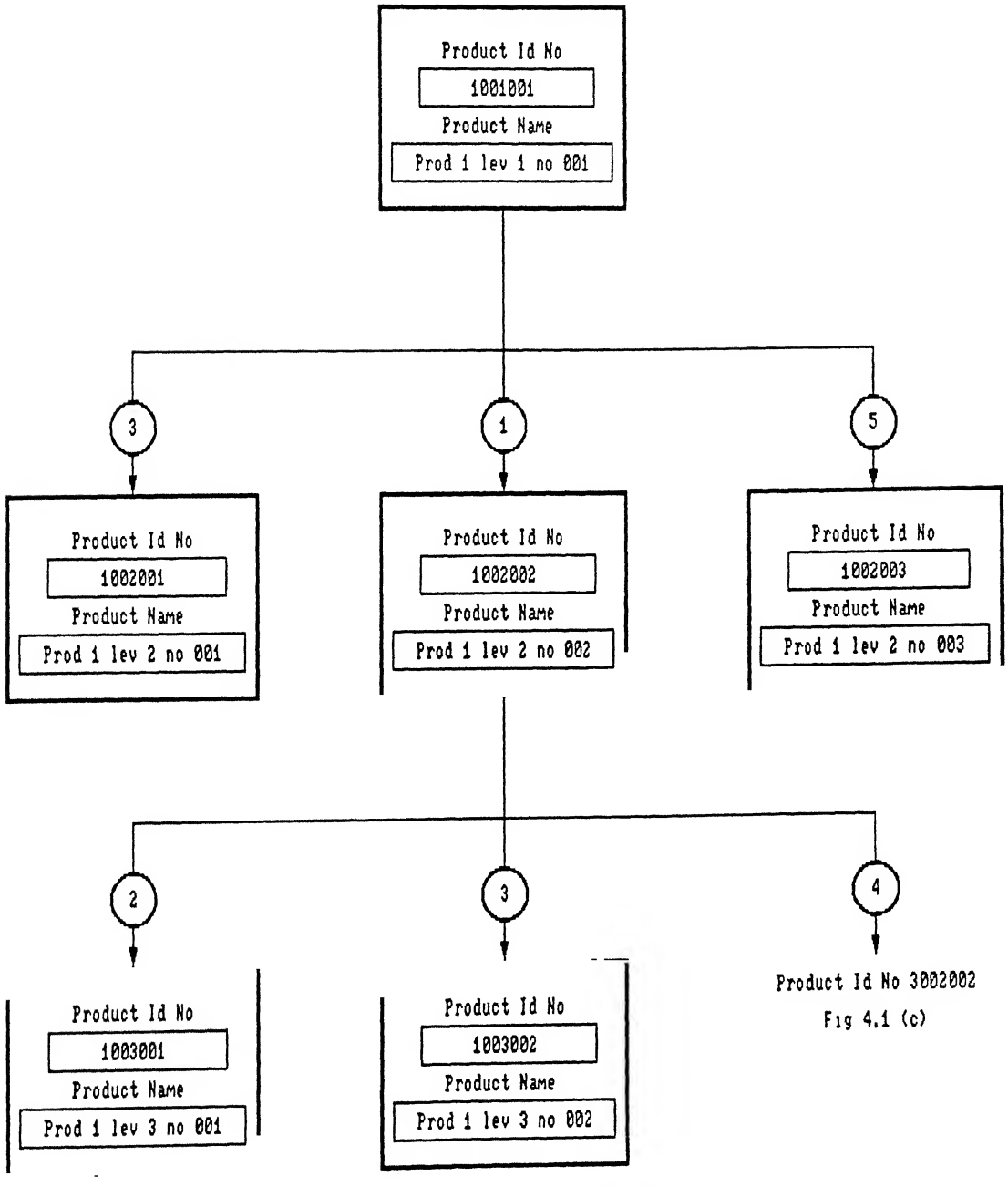


Figure 4.1 (a): Product structure (S.No:1)

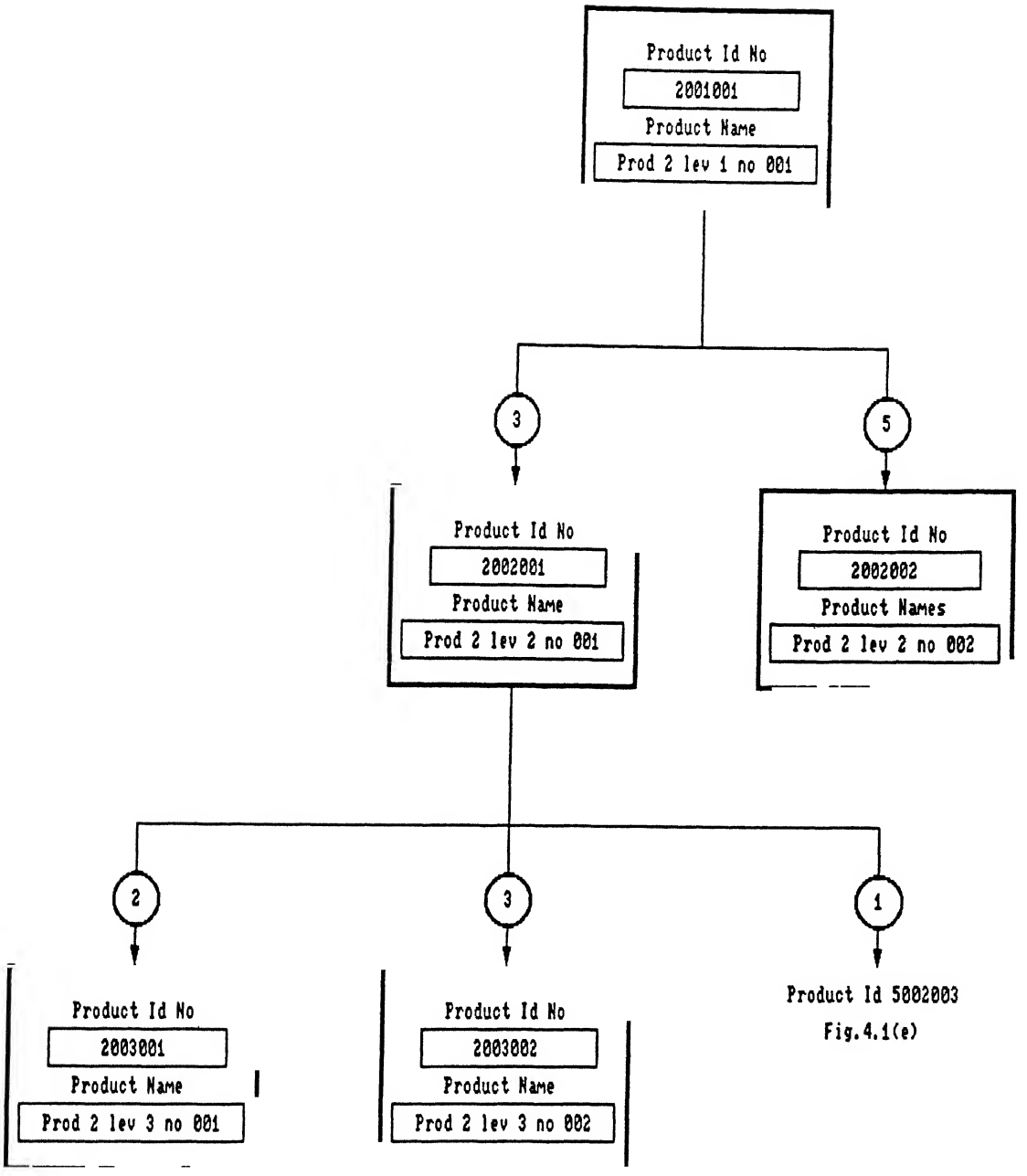


Figure 4.1 (b) : **Product structure (S.No:2)**

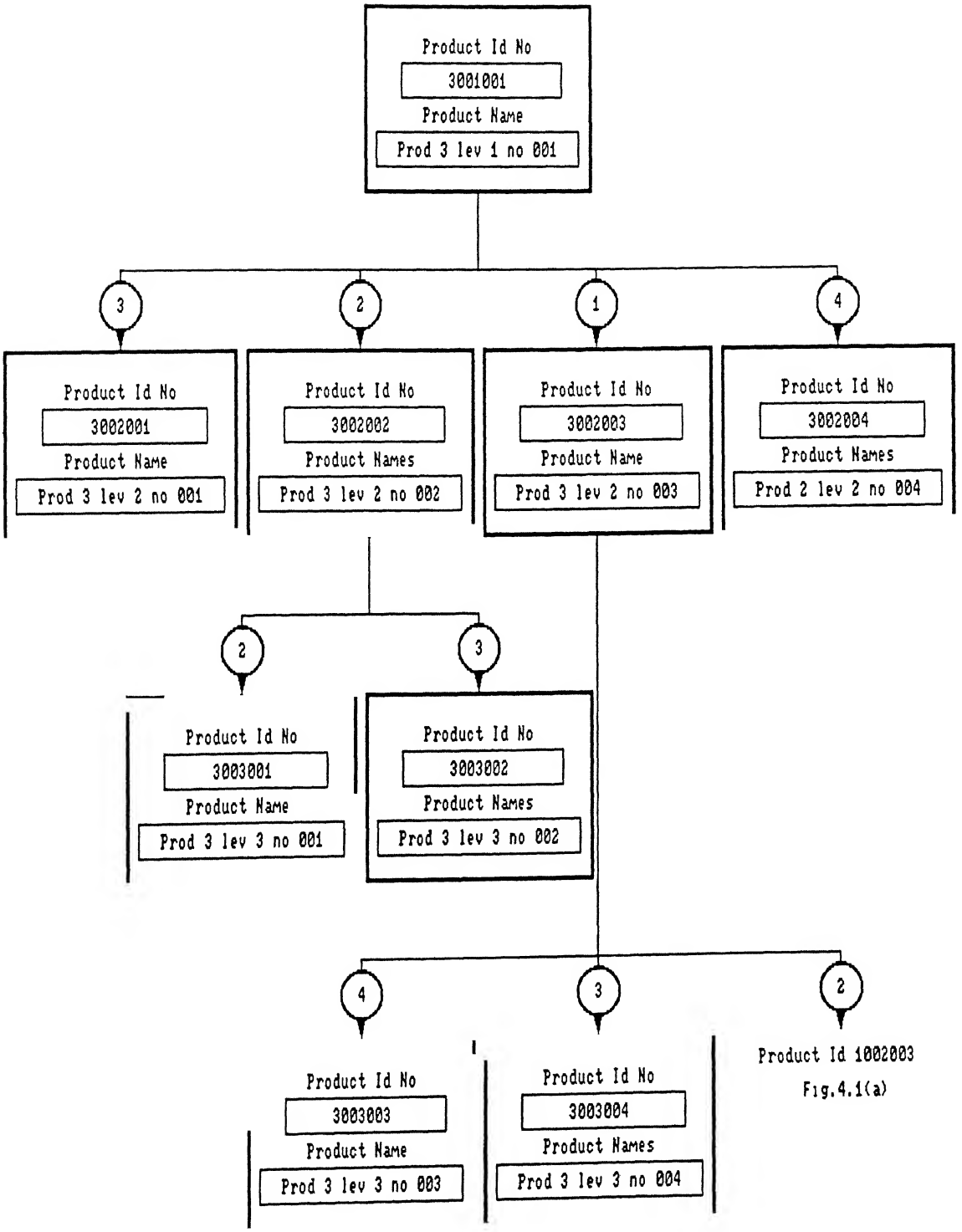


Figure 4.1 (c) : Product structure (S.No:3)

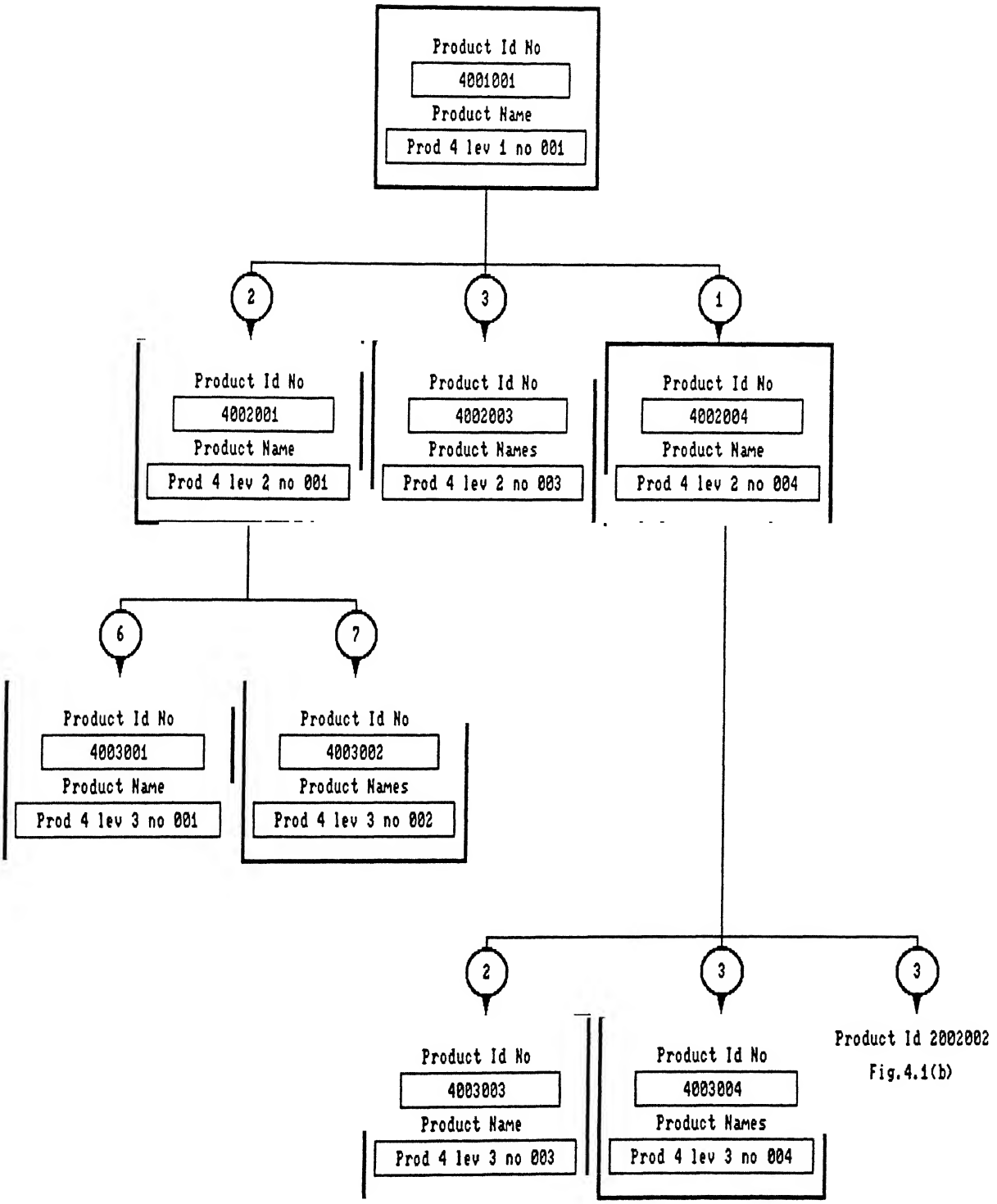


Figure 4.1 (d) : **Product structure (S.No:4)**

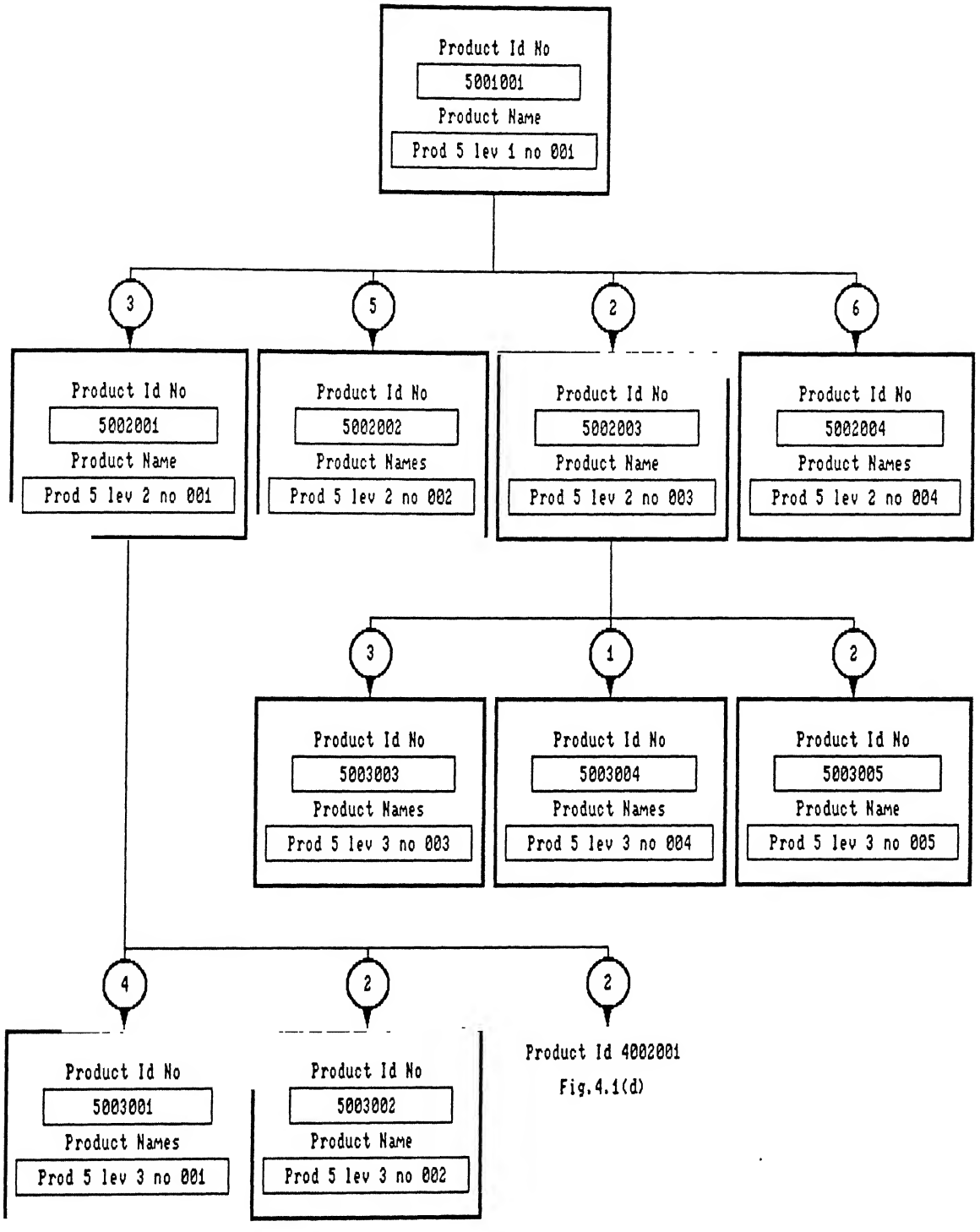


Fig.4.1(d)

Figure 4.1 (e) : Product structure (S.No:5)

Part features

Product Identification Number: 1002001

Product Name: Product 1 level 2 number 001

MATERIAL TYPE 4 | SURFACE FINISH LEVEL 1 | LARGEST DIMENSION 450 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
CYLINDERICAL SURFACE	450 mm	125 mm
THROUGH HOLE	10 mm	125 mm
CYCLOIDAL GEAR TEETH	450 mm	5 mm

Figure 4.2 (a) : PART FEATURES RECORD OF COMPONENT 1002001

Product Identification Number: 1002003

Product Name: Product1 level 2 number 003

MATERIAL TYPE 3 | SURFACE FINISH LEVEL 2 | LARGEST DIMENSION 950 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
PLANE FACE	250 mm	950 mm
U - SLOT	10 mm	950 mm
PLANE FACE	250 mm	50 mm

Figure 4.2 (b) : PART FEATURES RECORD OF COMPONENT 1002003

Product Identification Number

1003001

Product Name

Product 1 level 3 number 001

MATERIAL TYPE 6	SURFACE FINISH LEVEL 2	LARGEST DIMENSION 500 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
CYLINDRICAL SYRFACE	250 mm	500 mm
BORE HOLE	200 mm	500 mm
THROUGH HOLE	10 mm	125 mm
THREADS ON EXTERNAL SURFACE	250 mm	50 mm

Figure 4.2 (c) : PART FEATURES RECORD OF COMPONENT 1003001

Product Identoficaton Number

1003002

Product Name

Product1 level 3 number 002

MATERIAL TYPE 2	SURFACE FINISH LEVEL 4	LARGEST DIMENSION 250 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
TAPERED SURFACE	50 mm	250 mm
BLIND HOLE	10 mm	100 mm
INTERNAL THREADS	10 mm	100 mm

Figure 4.2 (d) : PART FEATURES RECORD OF COMPONENT 1003002

Product Identification Number	Product Name
2002002	Product 2 level 2 number 002

MATERIAL TYPE 2	SURFACE FINISH LEVEL 4	LARGEST DIMENSION 300 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
PLANE FACE	100 mm	300 mm
T - SLOT	50 mm	300 mm
THROUGH HOLE	8 mm	50 mm
INTERNAL THREADS	8 mm	50 mm

Figure 4.3 (a) : PART FEATURES RECORD OF COMPONENT 2002002

Product Identification Number	Product Name
2003001	Product 2 level 3 number 002

MATERIAL TYPE 7	SURFACE FINISH LEVEL 2	LARGEST DIMENSION 200 mm

FEATURE NAME	WIR.TH / DIAMETER	LENGTH
STEPPED CYLINDRICAL SURFACE	80 mm	200 mm
BLIND HOLE	10 mm	100 mm
INTERNAL THREADS	10 mm	100 mm

Figure 4.3 (c) : PART FEATURES RECORD OF COMPONENT 2003001

Product Identoficaton Number	Product Name
2003002	Product 2 level 3 number 002

MATERIAL TYPE 5	SURFACE FINISH LEVEL 1	LARGEST DIMENSION 300 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
KNUCKLED SURFACE	50 mm	300 mm
THROUGH HOLE	10 mm	300 mm
STEPPED HOLE	20 mm	100 mm

Figure 4.3 (b) : PART FEATURES RECORD OF COMPONENT 2002003

Product Identification Number	Product Name
3002001	Product 3 level 2 number 001

MATERIAL TYPE 6	SURFACE FINISH LEVEL 2	LARGEST DIMENSION 160 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
PLANE FACE	100 mm	160 mm
PLANE FACE WITH A CONCAVE EDGE	100 mm	160 mm
PLANE FACE WITH A CONCAVE EDGE	100 mm	125 mm
PLANE FACE	100 mm	125 mm

Figure 4.4 (a) : PART FEATURES RECORD OF COMPONENT 3002001

Product Identification Number	Product Name
3002004	Product 3 level 2 number 004

MATERIAL TYPE 3	SURFACE FINISH LEVEL 6	LARGEST DIMENSION 1000 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
CYLINDRICAL SURFACE	100 mm	1000 mm
THROUGH HOLE	80 mm	1000 mm

Figure 4.4 (b) : PART FEATURES RECORD OF COMPONENT 3002004

Product Identoficaton Number	Product Name
3003001	Product 3 level 3 number 001

MATERIAL TYPE 3	SURFACE FINISH LEVEL 4	LARGEST DIMENSION 350 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
PLANE FACE	350 mm	50 mm
THROUGH HOLE	50 mm	50 mm
CYCLOIDAL TEETH	350 mm	50 mm

Figure 4.4 (c) : PART FEATURES RECORD OF COMPONENT 3003001

Product Identification Number	Product Name
3003002	Product 3 level 3 number 002

MATERIAL TYPE 2	SURFACE FINISH LEVEL 1	LARGEST DIMENSION 450 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
CYLENDRICAL SURFACE	450 mm	100 mm
TAPERED HOLE	.50 mm	100 mm

Figure 4.4 (d) : PART FEATURES RECORD OF COMPONENT 3003002

Product Identoficaton Number	Product Name
3003003	Product 3 level 3 number 003

MATERIAL TYPE 6	SURFACE FINISH LEVEL 5	LARGEST DIMENSION 650 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
PLANE FACE	650 mm	100 mm
USER DEFINED PROFILE	650 mm	100 mm
PLANE FACE	650 mm	100 mm

Figure 4.4 (e) : PART FEATURES RECORD OF COMPONENT 3004003

Product Identification Number	Product Name
3003004	Product 3 level 3 number 004

MATERIAL TYPE 2	SURFACE FINISH LEVEL 3	LARGEST DIMENSION 350 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
PLANE FACE	350 mm	350 mm
INTERNAL RECTANGULAR SLOT	350 mm	100 mm

Figure 4.4 (f) : PART FEATURES RECORD OF COMPONENT 3004004

Product Identofication Number	Product Name
4002002	Product 4 level 2 number 002

MATERIAL TYPE 4	SURFACE FINISH LEVEL 1	LARGEST DIMENSION 3500 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
TAPERED SURFACE	500 mm	50 mm
THROUGH HOLE	350 mm	50 mm
INTERNAL THREADS	350 mm	50 mm

Figure 4.5 (a) : PART FEATURES RECORD OF COMPONENT 4002002

Product Identification Number	Product Name
4003001	Product 4 level 3 number 001

MATERIAL TYPE 5	SURFACE FINISH LEVEL 2	LARGEST DIMENSION 1500 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
PLANE FACE	1500 mm	500 mm
PLANE FACE	1500 mm	500 mm
PLANE FACE	1500 mm	125 mm
THREADS ON EXTERNAL SURFACE	250 mm	50 mm

Figure 4.5 (b) : PART FEATURES RECORD OF COMPONENT 4003001

Product Identoficaton Number	Product Name
4003002	Product 4 level 3 number 002

MATERIAL TYPE 2	SURFACE FINISH LEVEL 4	LARGEST DIMENSION 250 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
CYLENDRICAL SURFACE	50 mm	250 mm
TAPERED SURFACE	25 mm	250 mm
THROUGH HOLE	10 mm	100 mm

Figure 4.5 (c) : PART FEATURES RECORD OF COMPONENT 4003002

Product Identification Number	Product Name
5002002	Product 5 level 2 number 002

MATERIAL TYPE 2	SURFACE FINISH LEVEL 6	LARGEST DIMENSION 500 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
CYLINDRICAL SURFACE	80 mm	500 mm
BOREHOLE	60 mm	500 mm
EXTERNAL SPLINES	80 mm	500 mm

Figure 4.6 (a) : PART FEATURES RECORD OF COMPONENT 5002002

Product Identification Number	Product Name
5002004	Product 5 level 2 number 004

MATERIAL TYPE 7	SURFACE FINISH LEVEL 3	LARGEST DIMENSION 950 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
PLANE FACE	250 mm	950 mm
PLANE FACE	250 mm	950 mm
U - SLOT	10 mm	950 mm

Figure 4.6 (b) : PART FEATURES RECORD OF COMPONENT 5002004

Product Identoficaton Number: 5003001

Product Name: Product 5 level 3 number 001

MATERIAL TYPE 1 | SURFACE FINISH LEVEL 2 | LARGEST DIMENSION 1500 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
KNUCKLED SURFACE	150 mm	1500 mm
THROUGH HOLE	100 mm	1500 mm
STEPPED HOLE	20 mm	100 mm

Figure 4.6 (c) : PART FEATURES RECORD OF COMPONENT 5003001

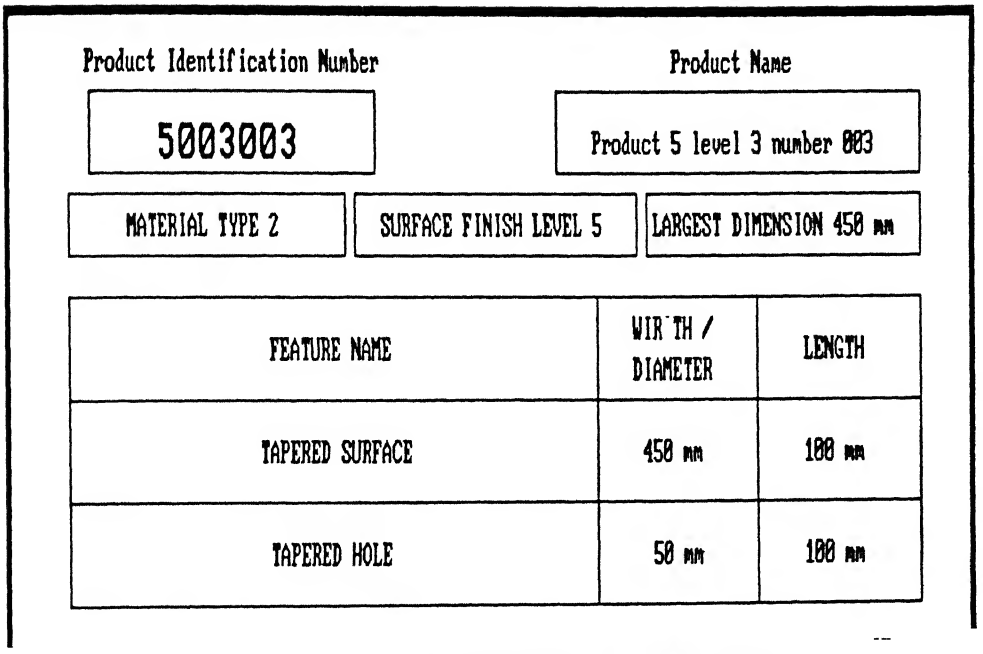
Product Identification Number: 5003002

Product Name: Product 5 level 3 number 002

MATERIAL TYPE 3 | SURFACE FINISH LEVEL 4 | LARGEST DIMENSION 1600 mm

FEATURE NAME	WIR TH / DIAMETER	LENGTH
PLANE FACE	100 mm	1600 mm
PLANE FACE	100 mm	1600 mm
PLANE FACE WITH A CONCAVE EDGE	100 mm	1600 mm
PLANE FACE	100 mm	1600 mm

Figure 4.6 (d) : PART FEATURES RECORD OF COMPONENT 5003002



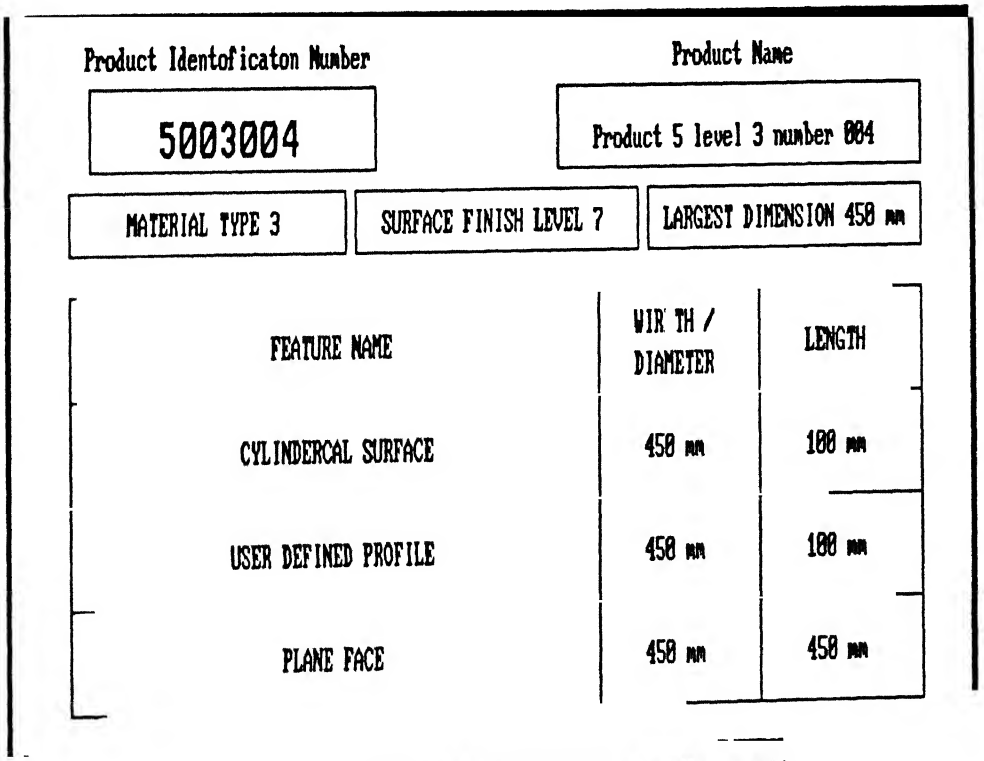
Product Identification Number: 5003003

Product Name: Product 5 level 3 number 003

MATERIAL TYPE 2 | SURFACE FINISH LEVEL 5 | LARGEST DIMENSION 450 mm

FEATURE NAME	WIDTH / DIAMETER	LENGTH
TAPERED SURFACE	450 mm	100 mm
TAPERED HOLE	50 mm	100 mm

Figure 4.6 (e) : PART FEATURES RECORD OF COMPONENT 5003003



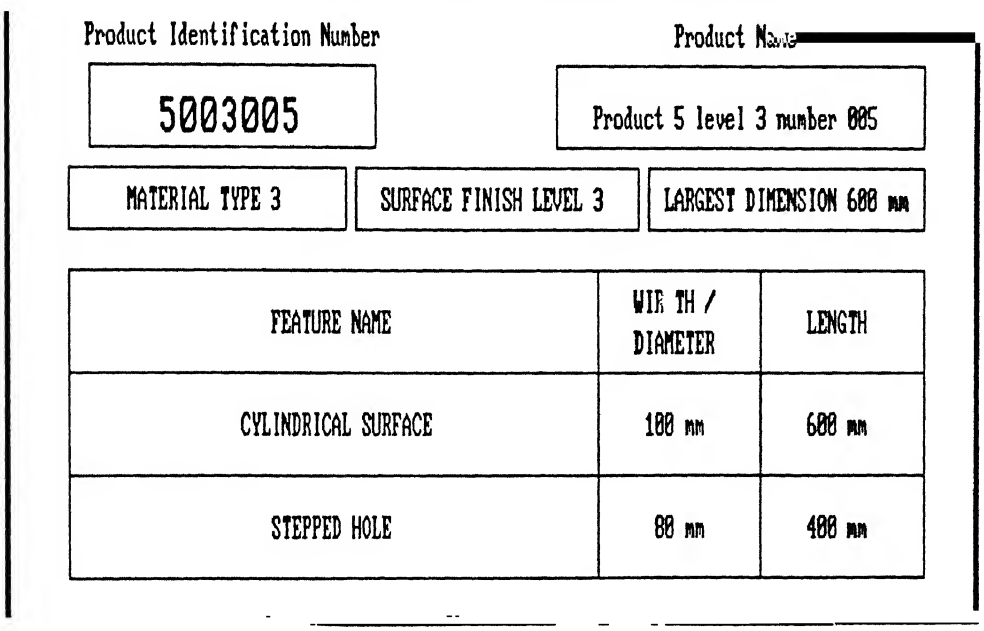
Product Identoficaton Number: 5003004

Product Name: Product 5 level 3 number 004

MATERIAL TYPE 3 | SURFACE FINISH LEVEL 7 | LARGEST DIMENSION 450 mm

FEATURE NAME	WIDTH / DIAMETER	LENGTH
CYLINDERCAL SURFACE	450 mm	100 mm
USER DEFINED PROFILE	450 mm	100 mm
PLANE FACE	450 mm	450 mm

Figure 4.6 (f) : PART FEATURES RECORD OF COMPONENT 5003004



Product Identification Number: 5003005

Product Name: Product 5 level 3 number 005

MATERIAL TYPE 3	SURFACE FINISH LEVEL 3	LARGEST DIMENSION 600 mm

FEATURE NAME	WIDTH / DIAMETER	LENGTH
CYLINDRICAL SURFACE	100 mm	600 mm
STEPPED HOLE	80 mm	400 mm

Figure 4.6 (g) : PART FEATURES RECORD OF COMPONENT 5003005

MACHINE Id. NUMBER

1001001

MACHINE TYPE

PLANER

MATERIAL TYPES

1	2	3	4	5	6	7	8
*	*	*			*	*	*

MAXIUM DIMENSION

1000 mm

OPERATIONS	m/c Speed
PLANE FACE (CONVEX EDGE)	34
U - SLOT	29

Figure 4.7 (a) : MACHINE CAPABILITY RECORD OF MACHINE 1001001

MACHINE Id. NUMBER

1001002

MACHINE TYPE

LATHE

MATERIAL TYPES

1	2	3	4	5	6	7	8
	*	*		*		*	

MAXIUM DIMENSION

500 mm

OPERATIONS	m/c Speed
CYLINDRICAL SURFACE	64
TAPERED SURFACE	67
SIDE FACE	53

Figure 4.7 (b) : MACHINE CAPABILITY RECORD OF MACHINE 1001002

MACHINE Id. NUMBER

1001003

MACHINE TYPE

DRILLING MACHINE

MATERIAL TYPES

1	2	3	4	5	6	7	8
*	*		*		*		*

MAXIUM DIMENSION

750 mm

OPERATIONS	m/c Speed
THROUGH HOLE	145
BLIND HOLE	152

Figure 4.7 (c) : MACHINE CAPABILITY RECORD OF MACHINE 1001003

MACHINE Id. NUMBER

1002001

MACHINE TYPE

LATHE

MATERIAL TYPES

1	2	3	4	5	6	7	8
*	*		*	*		*	

MAXIUM DIMENSION

1000 mm

OPERATIONS	m/c Speed
CYLINDRICAL SURFACE	23
STEPPED SURFACE	29
THREADED SURFACE	38
BOREHOLE	47

Figure 4.7 (d) : MACHINE CAPABILITY RECORD OF MACHINE 1002001

MACHINE Id. NUMBER

1002002

MACHINE TYPE

HORIZONTAL MILLING

MATERIAL TYPES

1	2	3	4	5	6	7	8
*		*		*		*	

MAXIUM DIMENSION

750 mm

OPERATIONS	m/c Speed
SLOTTING	77
GEAR TEETH (INVOLUTE)	132

Figure 4.7 (e) : MACHINE CAPABILITY RECORD OF MACHINE 1002002

MACHINE Id. NUMBER

1002003

MACHINE TYPE

DRILLING

MATERIAL TYPES

1	2	3	4	5	6	7	8
*	*	*	*			*	*

MAXIUM DIMENSION

800 mm

OPERATIONS	m/c Speed
TAPERED HOLE	127

Figure 4.7 (f) : MACHINE CAPABILITY RECORD OF MACHINE 1002003

MACHINE Id. NUMBER: 1003001

MACHINE TYPE: VERTICAL MILLING

MATERIAL TYPES

1	2	3	4	5	6	7	8
*		*		*			*

MAXIUM DIMENSION: 1500 mm

OPERATIONS	m/c Speed
FACE MILLING	25
LENEAR SLOTS	55
COMPLEX FORM	77

Figure 4.7 (g) : MACHINE CAPABILITY RECORD OF MACHINE 1003001

MACHINE Id. NUMBER: 1003002

MACHINE TYPE: SHAPER

MATERIAL TYPES

1	2	3	4	5	6	7	8
*	*	*	*		*	*	*

MAXIUM DIMENSION: 4500 mm

OPERATIONS	m/c Speed
PLANE FACE (CONVEX EDGE)	33
T - SLOT	57
PLANE FACE (CONCAVE EDGE)	37

Figure 4.7 (h) : MACHINE CAPABILITY RECORD OF MACHINE 1003002

MACHINE Id. NUMBER: 1003003

MACHINE TYPE: LATHE

MATERIAL TYPES

1	2	3	4	5	6	7	8
*	*	*		*	*		*

MAXIUM DIMENSION: 2000 mm

OPERATIONS	m/c Speed
CYLINDRICAL SURFACE	123
STEPPED SURFACE	133
BLIND HOLE	277
THROUGH HOLE	235

Figure 4.7 (i) : MACHINE CAPABILITY RECORD OF MACHINE 1003003

MACHINE Id. NUMBER

1004001

MACHINE TYPE

LATHE

MATERIAL TYPES

1	2	3	4	5	6	7	8
*	*	*		*	*	*	

MAXIUM DIMENSION

700 mm

OPERATIONS	m/c Speed
CYLINDRICAL SURFACE	57
STEPPED SYRFACE	63
THREADED SURFACE	68

Figure 4.7 (j) : MACHINE CAPABILITY RECORD OF MACHINE 1004002

MACHINE Id. NUMBER

1004002

MACHINE TYPE

VERTICAL MILLING

MATERIAL TYPES

1	2	3	4	5	6	7	8
	*	*	*	*	*	*	

MAXIUM DIMENSION

750 mm

OPERATIONS	m/c Speed
FACE MILLING	134
COMPLEX FORM	154
BORING	163

Figure 4.7 (k) : MACHINE CAPABILITY RECORD OF MACHINE 1004002

MACHINE Id. NUMBER

1004003

MACHINE TYPE

HORIZONTAL MILLING

MATERIAL TYPES

1	2	3	4	5	6	7	8
*	*	*	*	*		*	*

MAXIUM DIMENSION

1350 mm

OPERATIONS	m/c Speed
SLOTTING	233
GEAR TEETH (CYCLOIDAL)	311
GEAR TEETH (INVOLUTE)	301
NON - STANDARD TEETH	333

Figure 4.7 (l) : MACHINE CAPABILITY RECORD OF MACHINE 1004003

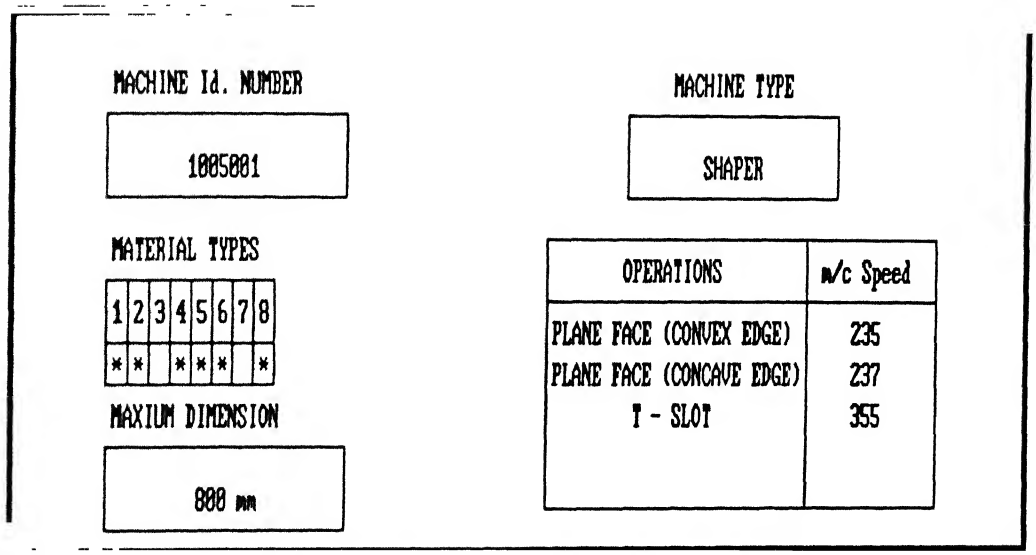


Figure 4.7 (m) : MACHINE CAPABILITY RECORD OF MACHINE 1005001

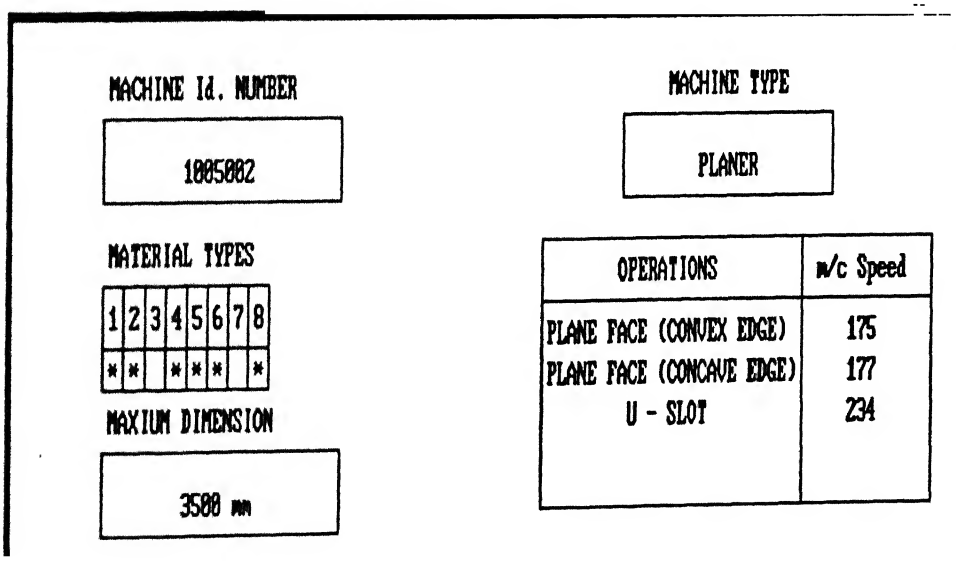


Figure 4.7 (n) : MACHINE CAPABILITY RECORD OF MACHINE 1005002

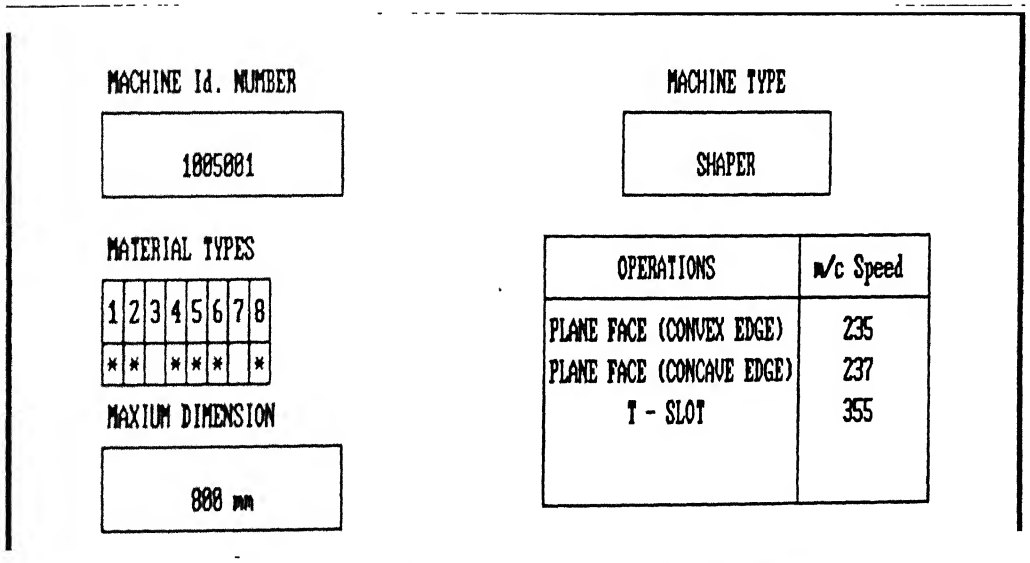


Figure 4.7 (m) : MACHINE CAPABILITY RECORD OF MACHINE 1005001

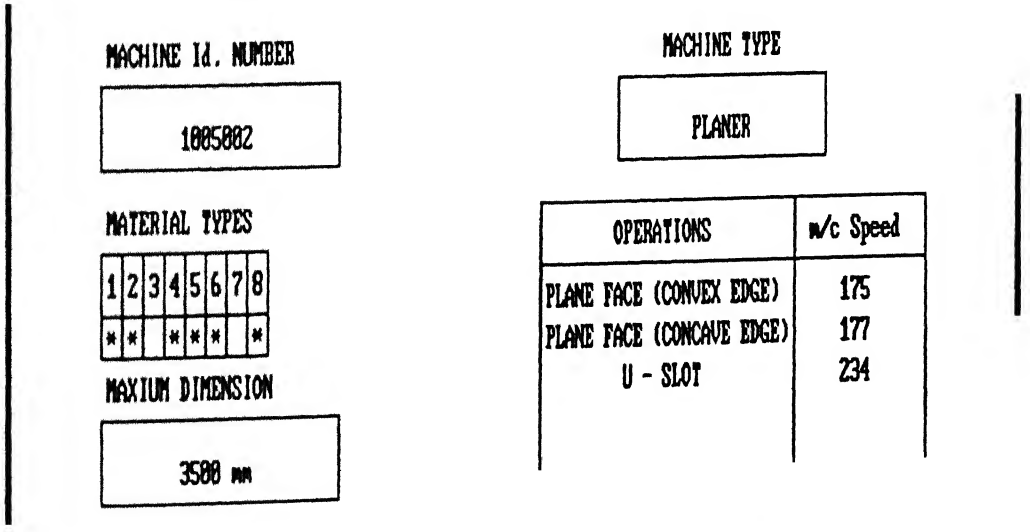


Figure 4.7 (n) : MACHINE CAPABILITY RECORD OF MACHINE 1005002

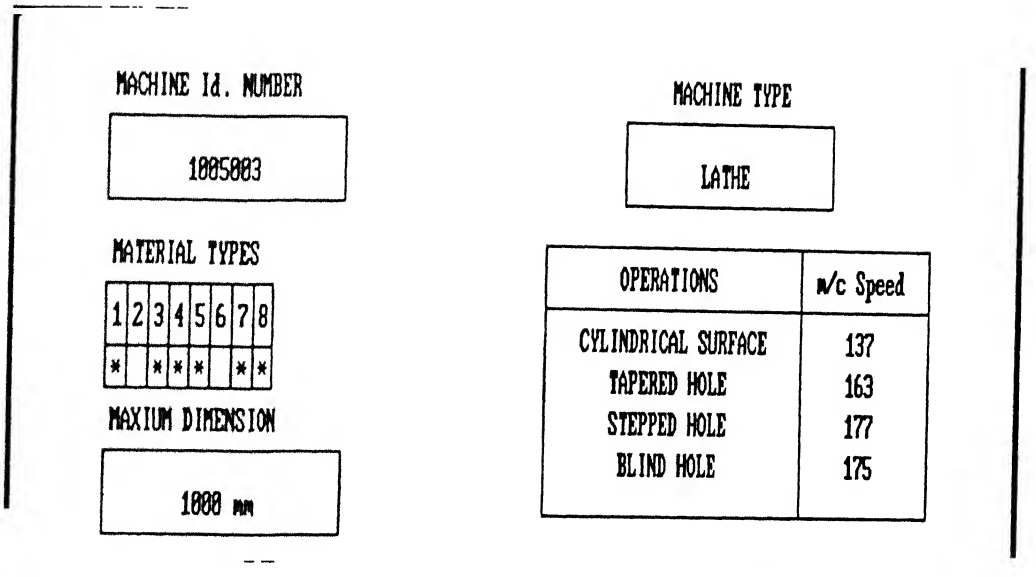


Figure 4.7 (o) : MACHINE CAPABILITY RECORD OF MACHINE 1005003

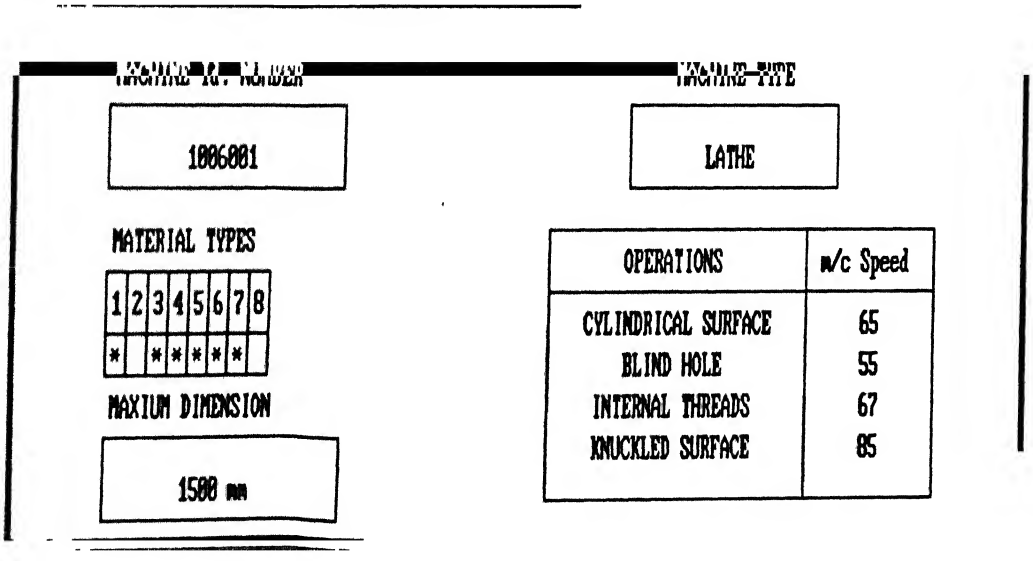


Figure 4.7 (p) : MACHINE CAPABILITY RECORD OF MACHINE 1006001

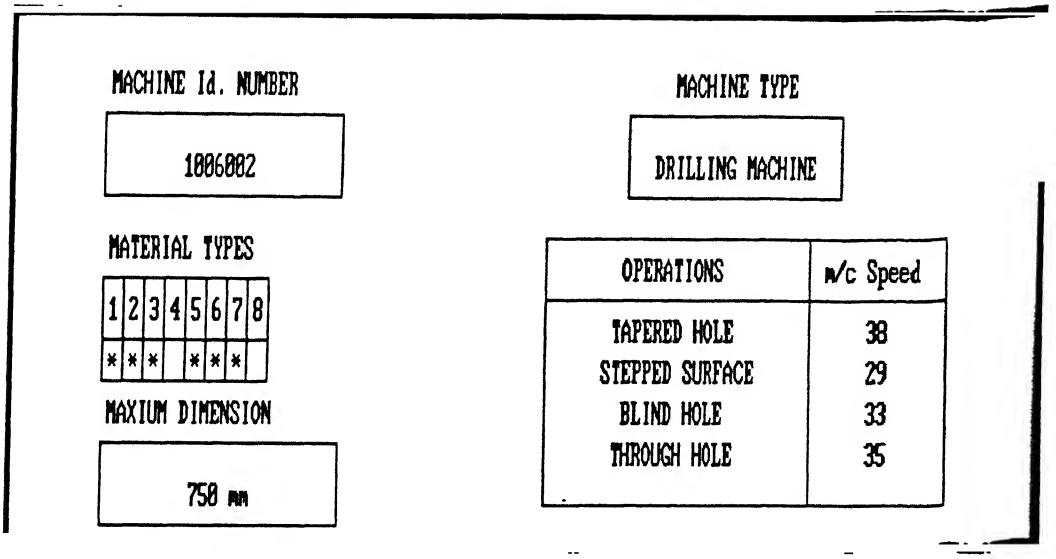


Figure 4.7 (q) : MACHINE CAPABILITY RECORD OF MACHINE 1006002

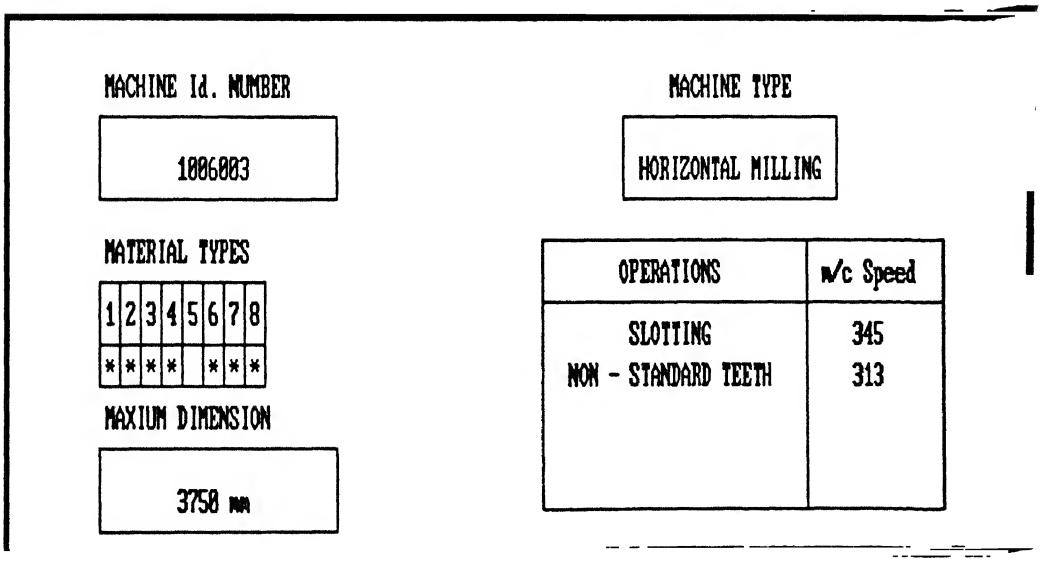


Figure 4.7 (r) : MACHINE CAPABILITY RECORD OF MACHINE 1006003

Part Id 1002002 Part Name Prod 1 lev 2 no 002
Level 1 Quantity 1
Has further subassemblies:
Part Id 1003001 Part Name Prod 1 lev 3 no 001
Part Id 1003002 Part Name Prod 1 lev 3 no 002
Part Id 3002002 Part Name Prod 3 lev 2 no 002

Part Id 1003001 Part Name Prod 1 lev 3 no 001
Level 2 Quantity 2 Is an end item.

Part Id 1003002 Part Name Prod 1 lev 3 no 002
Level 2 Quantity 3 Is an end item.

Part Id 3002002 Part Name Prod 3 lev 2 no 002
Level 2 Quantity 4
Has further subassemblies:
Part Id 3003001 Part Name Prod 3 lev 3 no 001
Part Id 3003002 Part Name Prod 3 lev 3 no 002

Part Id 3003001 Part Name Prod 3 lev 3 no 001
Level 3 Quantity 8 Is an end item.

Part Id 3003002 Part Name Prod 3 lev 3 no 002
Level 3 Quantity 12 Is an end item.

Part Id 1002003 Part Name Prod 1 lev 2 no 003
Level 1 Quantity 5 Is an end item.

Part Id 2001001 Part Name Prod 2 lev 1 no 001
Level 0 Quantity 1
Has further subassemblies:
Part Id 2002001 Part Name Prod 2 lev 2 no 001
Part Id 2002002 Part Name Prod 2 lev 2 no 002

Part Id 2002001 Part Name Prod 2 lev 2 no 001
Level 1 Quantity 3
Has further subassemblies:
Part Id 2003001 Part Name Prod 2 lev 3 no 001
Part Id 2003002 Part Name Prod 2 lev 3 no 002
Part Id 5002003 Part Name Prod 5 lev 2 no 003

Part Id 2003001 Part Name Prod 2 lev 3 no 001
Level 2 Quantity 6 Is an end item.

Part Id 2003002 Part Name Prod 2 lev 3 no 002
Level 2 Quantity 9 Is an end item.

Part Id 5002003 Part Name Prod 5 lev 2 no 003
Level 2 Quantity 3
Has further subassemblies:
Part Id 5003003 Part Name Prod 5 lev 3 no 003
Part Id 5003004 Part Name Prod 5 lev 3 no 004
Part Id 5003005 Part Name Prod 5 lev 3 no 005

Part Id 5003003 Part Name Prod 5 lev 3 no 003
Level 3 Quantity 9 Is an end item.

Part Id 5003004 Part Name Prod 5 lev 3 no 004

Level 3 Quantity 3 Is an end item.

Part Id 5003005 Part Name Prod 5 lev 3 no 005
Level 3 Quantity 6 Is an end item.

Part Id 2002002 Part Name Prod 2 lev 2 no 002
Level 1 Quantity 5 Is an end item.

Part Id 3001001 Part Name Prod 3 lev 1 no 001
Level 0 Quantity 1
Has further subassemblies.
Part Id 3002001 Part Name Prod 3 lev 2 no 001
Part Id 3002002 Part Name Prod 3 lev 2 no 002
Part Id 3002003 Part Name Prod 3 lev 2 no 003
Part Id 3002004 Part Name Prod 3 lev 2 no 004

Part Id 3002001 Part Name Prod 3 lev 2 no 001
Level 1 Quantity 3 Is an end item.

Part Id 3002002 Part Name Prod 3 lev 2 no 002
Level 1 Quantity 2
Has further subassemblies:
Part Id 3003001 Part Name Prod 3 lev 3 no 001
Part Id 3003002 Part Name Prod 3 lev 3 no 002

Part Id 3003001 Part Name Prod 3 lev 3 no 001
Level 2 Quantity 4 Is an end item.

Part Id 3003002 Part Name Prod 3 lev 3 no 002
Level 2 Quantity 6 Is an end item.

Part Id 3002003 Part Name Prod 3 lev 2 no 003
Level 1 Quantity 1
Has further subassemblies:
Part Id 3003003 Part Name Prod 3 lev 3 no 003
Part Id 3003004 Part Name Prod 3 lev 3 no 004
Part Id 1002003 Part Name Prod 1 lev 2 no 003

Part Id 3003003 Part Name Prod 3 lev 3 no 003
Level 2 Quantity 4 Is an end item.

Part Id 3003004 Part Name Prod 3 lev 3 no 004
Level 2 Quantity 3 Is an end item.

Part Id 1002003 Part Name Prod 1 lev 2 no 003
Level 2 Quantity 2 Is an end item.

Part Id 3002004 Part Name Prod 3 lev 2 no 004
Level 1 Quantity 4 Is an end item.

Part Id 4001001 Part Name Prod 4 lev 1 no 001
Level 0 Quantity 1
Has further subassemblies:
Part Id 4002001 Part Name Prod 4 lev 2 no 001
Part Id 4002002 Part Name Prod 4 lev 2 no 002
Part Id 4002003 Part Name Prod 4 lev 2 no 003

Part Id 4002001 Part Name Prod 4 lev 2 no 001

Level 1 Quantity 2
Has further subassemblies:
Part Id 4003001 Part Name Prod 4 lev 3 no 001
Part Id 4003002 Part Name Prod 4 lev 3 no 002

Part Id 4003001 Part Name Prod 4 lev 3 no 001
Level 2 Quantity 12 Is an end item.

Part Id 4003002 Part Name Prod 4 lev 3 no 002
Level 2 Quantity 14 Is an end item.

Part Id 4002002 Part Name Prod 4 lev 2 no 002
Level 1 Quantity 3 Is an end item.

Part Id 4002003 Part Name Prod 4 lev 2 no 003
Level 1 Quantity 1
Has further subassemblies:
Part Id 4003003 Part Name Prod 4 lev 3 no 003
Part Id 4003004 Part Name Prod 4 lev 3 no 004
Part Id 2002002 Part Name Prod 2 lev 2 no 002

Part Id 4003003 Part Name Prod 4 lev 3 no 003
Level 2 Quantity 2 Is an end item.

Part Id 4003004 Part Name Prod 4 lev 3 no 004
Level 2 Quantity 3 Is an end item.

Part Id 2002002 Part Name Prod 2 lev 2 no 002
Level 2 Quantity 3 Is an end item.

Part Id 5001001 Part Name Prod 5 lev 1 no 001
Level 0 Quantity 1
Has further subassemblies:
Part Id 5002001 Part Name Prod 5 lev 2 no 001
Part Id 5002002 Part Name Prod 5 lev 2 no 002
Part Id 5002003 Part Name Prod 5 lev 2 no 003
Part Id 5002004 Part Name Prod 5 lev 2 no 004

Part Id 5002001 Part Name Prod 5 lev 2 no 001
Level 1 Quantity 3
Has further subassemblies:
Part Id 5003001 Part Name Prod 5 lev 3 no 001
Part Id 5003002 Part Name Prod 5 lev 3 no 002
Part Id 4002001 Part Name Prod 4 lev 2 no 001

Part Id 5003001 Part Name Prod 5 lev 3 no 001
Level 2 Quantity 12 Is an end item.

Part Id 5003002 Part Name Prod 5 lev 3 no 002
Level 2 Quantity 6 Is an end item.

Part Id 4002001 Part Name Prod 4 lev 2 no 001
Level 2 Quantity 6
Has further subassemblies:
Part Id 4003001 Part Name Prod 4 lev 3 no 001
Part Id 4003002 Part Name Prod 4 lev 3 no 002

Part Id 4003001 Part Name Prod 4 lev 3 no 001

Level 3 Quantity 36 Is an end item.

Part Id 4003002 Part Name Prod 4 lev 3 no 002
Level 3 Quantity 42 Is an end item.

Part Id 5002002 Part Name Prod 5 lev 2 no 002
Level 1 Quantity 5 Is an end item

Part Id 5002003 Part Name Prod 5 lev 2 no 003
Level 1 Quantity 2
Has further subassemblies
Part Id 5003003 Part Name Prod 5 lev 3 no 003
Part Id 5003004 Part Name Prod 5 lev 3 no 004
Part Id 5003005 Part Name Prod 5 lev 3 no 005

Part Id 5003003 Part Name Prod 5 lev 3 no 003
Level 2 Quantity 6 Is an end item.

Part Id 5003004 Part Name Prod 5 lev 3 no 004
Level 2 Quantity 2 Is an end item.

Part Id 5003005 Part Name Prod 5 lev 3 no 005
Level 2 Quantity 4 Is an end item.

Part Id 5002004 Part Name Prod 5 lev 2 no 004
Level 1 Quantity 6 Is an end item.

Cross checking the output manually establishes that the generated bill of materials are accurate. The bill of materials are do not depend on the quantity of product to be produced. Only the inclusion or exclusion of a product from the file affects the output.

4.3 PROCESS PLAN

The process plan for the end components of the products in the demand file is generated by activating the "**select machines**" menu item. The output of the system is reproduced below.

PART Id 1002001 Quantity 6
Operation 1 1002001 1006001 1005003
Operation 2 1003002 1002001 1006001 1002003 1001003
Operation 3 1006001 1002003 1001003

PART Id 1002003 Quantity 12
Operation 1 1001001 1003002 1003001 1006001 1005003
Operation 2 1001001 1003002 1003001 1006001 1005002

Operation 3 1001001 1003002 1003001 1006001 1005003

PART Id 1003001 Quantity 4
Operation 1 1004001 1006001 1003003
Operation 2 1001001 1006002 1003002 1004001 1006001
Operation 3 1001001 1006002 1003002 1004001 1006001
Operation 4 1004001 1006001 1003003

PART Id 1003002 Quantity 6
Operation 1 1002001 1001002 1004001 1003003 1006003
Operation 2 1006002 1002001 1001002 1004001 1002003
Operation 3 1006002 1003002 1002001 1001002 1004001

PART Id 2002002 Quantity 30
Operation 1 1001001 1003002 1002001 1001002 1004001
Operation 2 1001001 1003002 1004002 1005002 1006003
Operation 3 1001001 1006002 1003002 1002001 1001002
Operation 4 1006002 1003002 1002001 1001002 1004001

PART Id 2003001 Quantity 18
Operation 1 1002001 1001002 1004001 1006001 1005003
Operation 2 1006002 1002001 1001002 1004001 1006001
Operation 3 1006002 1003002 1002001 1001002 1004001

PART Id 2003002 Quantity 27
Operation 1 1006002 1002001 1001002 1004001 1006001
Operation 2 1006002 1002001 1001002 1004001 1006001
Operation 3 1006002 1002001 1001002 1004001 1006001

PART Id 3002001 Quantity 3
Operation 1 1001001 1003002 1004001 1006001 1004002
Operation 2 1001001 1003002 1006001 1004002 1005002
Operation 3 1001001 1003002 1006001 1004002 1005002
Operation 4 1001001 1003002 1004001 1006001 1004002

PART Id 3002004 Quantity 4
Operation 1 1006001 1003003
Operation 2 1003002 1006001 1005002 1003003

PART Id 3003001 Quantity 20
Operation 1 1001001 1003002 1001002 1004001 1003001
Operation 2 1001001 1006002 1003002 1001002 1004001
Operation 3 1006002 1006001 1002003

PART Id 3003002 Quantity 30
Operation 1 1002001 1001002 1004001 1003003
Operation 2 1001001 1006002 1003002 1002001 1001002

PART Id 3003003 Quantity 4
Operation 1 1001001 1003002 1004001 1006001 1004002
Operation 2 1006002 1001003 1004002
Operation 3 1001001 1003002 1004001 1006001 1004002

PART Id 3003004 Quantity 3
Operation 1 1001001 1003002 1002001 1001002 1004001
Operation 2 1004002 1006003 1004003

PART Id 4002002 Quantity 15

Operation 1 1002001 1006001 1005003 1006003 1004003
Operation 2 1003002 1002001 1006001 1002003 1001003
Operation 3 1003002 1002001 1006001 1005003

PART Id 4003001 Quantity 564
Operation 1 1003003
Operation 2 1003003
Operation 3 1003003
Operation 4 1003003

PART Id 4003002 Quantity 658
Operation 1 1002001 1001002 1004001 1003003
Operation 2 1002001 1001002 1004001 1003003 1006003
Operation 3 1001001 1006002 1003002 1002001 1001002

PART Id 4003003 Quantity 10
Operation 1 1001002 1004001 1006001 1005003 1003003
Operation 2 1006002 1001002 1004001 1003001 1006001

PART Id 4003004 Quantity 15
Operation 1 1001001 1003002 1001002 1004001 1003001
Operation 2 1001001 1006002 1003002 1001002 1004001
Operation 3 1006002 1004001 1002003 1006003 1004003

PART Id 5002002 Quantity 70
Operation 1 1002001 1004001 1003003
Operation 2 1001001 1006002 1003002 1002001 1004001
Operation 3 1006002 1002003 1001003 1004003

PART Id 5002004 Quantity 84
Operation 1 1001001 1003002 1002001 1006001 1005003
Operation 2 1001001 1003002 1002001 1006001 1005003
Operation 3 1001001 1003002 1006001 1005002 1006003

PART Id 5003001 Quantity 168
Operation 1 1003002 1005002 1003003
Operation 2 1003002 1005002 1003003
Operation 3 1003003

PART Id 5003002 Quantity 84
Operation 1 1003002 1005002 1003003 1006003
Operation 2 1003002 1005002 1003003 1006003
Operation 3 1003002 1005002 1006003
Operation 4 1003002 1005002 1003003 1006003

PART Id 5003003 Quantity 111
Operation 1 1002001 1001002 1004001 1003003 1006003
Operation 2 1001001 1006002 1003002 1002001 1001002

PART Id 5003004 Quantity 37
Operation 1 1001002 1004001 1006001 1005003 1003003
Operation 2 1006002 1002003 1004002 1005003
Operation 3 1001001 1003002 1001002 1004001 1003001

PART Id 5003005 Quantity 74
Operation 1 1004001 1006001 1005003 1003003
Operation 2 1006002 1004001 1006001 1002003 1004002

The end components that are to be produced for assembling the products in the demand file are listed in the output. Corresponding to each end component the following information is displayed.

(a) The quantity in which the end component is required

(b) The operations required for manufacturing the component and the list of identification numbers of the machines that can perform each operation The machines are listed in the decreasing order of their suitability for performing the given operation

Consider the first operation in the production of component 1002001. The operation is required to produce a cylindrical surface (Fig 3.2 (c)). The qualified machines; 1002001, 1006001 and 1005003 are lathes. All of these machines can machine material of type 4 and can handle parts larger than 450mm. Other lathes in the data base; 1003003 and 1004001 can not handle material of type 4. Their exclusion from the final list is therefore rational. The machines have been listed in the increasing order of machining time; i.e. in the decreasing order of their suitability.

In order to test the system the data of machine 1002001 is changed slightly. The maximum size of the parts that the machine can handle is reduced to 400mm. The relevant portion of the output is displayed below:

PART Id 1002001 Quantity 6
Operation 1 1006001 1005003
Operation 2 1003002 1006001 1002003 1001003 1005003
Operation 3 1006001 1002003 1001003

The output does not include machine 1002001. Next the machine data of machine 1003003 is changed Material of type 4 is now included in the included

in the set of materials that the machine can handle. The relevant portion of the systems output is displayed below.

PART Id 1002001 Quantity 6
Operation 1 1006001 1005003 1003003
Operation 2 1003002 1006001 1002003 1001003 1005003
Operation 3 1006001 1002003 1001003

The output include machine 1002001. The system therefore performs the selection operation on the basis of all the criterion that it was designed to consider.

Next operation 1 of part 1002003 is considered. The feature to be machined is a plane face. The list of selected machines for this operations are 1001001, 1003002, 1003001, 1006001 and 1005003 These machines are planer, shaper, horizontal milling machine, horizontal milling machine and planner respectively. The system therefore evaluates all types of machines before making the final selection.

CHAPTER V

CONCLUSION AND SCOPE OF FUTURE RESEARCH

The present work synthesizes two schemes of CAPP; the generative and the variant system to evolve a practical and workable solution to the problem of machine selection. In devising a solution to the proposed problem it has been our endeavor to exploit the full potential of the techniques used. The power and potential of the proposed system is clearly demonstrated in the results that have been achieved. At the same time it was felt that the usefulness of the system would be greatly augmented if the list of part features and the machine capability is made more extensive. In the present work it is assumed that part features can be machined in a single operation. The extension of the term to cover entities that require more than one machining operation would make the system more general and rational.

The addition of an engine for generating part features from CAD output will be improve the utility of the system. On the other hand the output of the system can be used as input for a computerized scheduling system. The designed system generates a set of suitable machine for each machining operation. This will allow certain flexibility in the scheduling operation. The incorporation of the proposed extensions to the present system will result in an integrated process planning and scheduling system.

There is sufficient scope to adapt the analytical framework and final code of the present work to deal with a problem different from the one that has been targeted at. Subsections of the solution can be used in dealing with an entirely different problem in operations management or automated production planning.

The use of C++, an object oriented programming language was found to simplify the implementation to a large extend. Object orientation is helpful in dealing with situations that are difficult to analyze but easy to model The issues dealt with in the present work fit this description. The use of object oriented approach to design a system for deriving machining sequence from the list of part features therefore promises to be an interesting exercise

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